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DEVELOPMENT OF PLAGIOCLASE PORPHYROBLASTS[1]

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ABSTRACT

Porphyroblastic textures are common to hornfels in the Cornucopia area of the Wallowa Mountains of northeastern Oregon. Recent petrographic studies indicate that they are also common to some of the rocks of the Cascades of Washington. Plagioclase porphyroblasts range from initial allotrioblastic forms to fully developed idioblastic crystals. They exhibit many characteristic features which may include poikioblastic structures, helizitic inclusions and complex aggregates. The arrangement within the crystal of inclusions of either identifiable minerals or turbid material, is apparently directly related to the stage of development of the porphyroblast. This included matter differs chiefly in its arrangement from the products of endogenetic or subsequent alteration.

Recognition of these metamorphic textures and structures is one of the points essential to the interpretation of recrystallization-replacement as applied to igneous-appearing rocks which are believed to have been formed in situ by processes of additive hydrothermal metamorphism.

In a previous paper the writer outlined the development of quartz porphyroblasts in a siliceous hornfels.[2] The quartz porphyroblasts in the siliceous hornfels were too small (0.5 mm.) to be conspicuous in the hand specimens, but were readily seen under crossed nicols, although in plane light they merged almost completely with the groundmass of the hornfels, and contained the same abundance of small inclusions as the groundmass. The siliceous hornfels is not the most abundant; biotitic and hornblendic varieties are far more common. They vary in color from dark green to black, although in surface exposures the prevailing color is brown due to the oxidation of minute disseminated grains and veinlets of pyrite.

These hornfels form a part of the metamorphic rocks of the Wallowa Mountains of northeastern Oregon, where in the vicinity of the mining town of Cornucopia, pre-Tertiary sediments and volcanics are now metamorphosed to schists, hornfels and greenstones, and are adjacent to emplacements of granodioritic and associated rocks such as porphyries, granophyres, aplites, pegmatites and quartz veins.

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[1] Presented to the Cordilleran Section, Geological Society of America, Berkeley, California, April 1937.

[2] Goodspeed, G. E., Development of quartz porphyroblasts in a siliceous hornfels: *Am. Mineral.*, vol. **22**, pp. 133–138, 1937.

Petrographic study of many specimens from underground mine workings as well as the surface outcrops shows that the hornfels varies considerably in microtexture and structure. In some of the finer grained varieties, the interlocking crystals of the groundmass are so small as to be barely distinguishable, while in the coarser varieties the microtexture approaches that of a granulite. Most hornfels sections show a xenoblastic intergrowth of unstriated plagioclase, quartz, biotite and hornblende. The two latter minerals commonly exhibit some alignment, and either mineral may predominate. This suggests a period of dynamic metamorphism preceding that of thermal metamorphism. In some sections, however, a decussate structure is present, and a few sections appear to be typical "garbenschiefer" with plumed porphyroblasts of anthophyllite. Other sections contain varying amounts of garnet, diopside, epidote, titanite, chlorite, magnetite and pyrite. Garnet, diopside and epidote occur in irregular patches and lenticular veinlets which probably are similar in origin to the quartz-diopside-garnet veinlets commonly found in this area.[3]

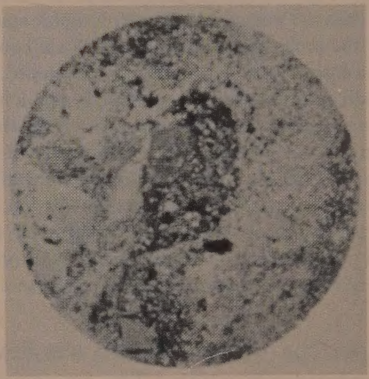

Fig. 1. Development of a plagioclase porphyroblast showing a shadow-like extension from a clear nucleus. The incipient porphyroblast shown in the photomicrograph is 1.5 mm. in length.

Porphyroblastic textures are common. Some of the plagioclase porphyroblasts are from 2 to 5 mm. in size, so that megascopically the hornfels may easily be mistaken for a dark colored porphyritic igneous rock. Under the microscope the porphyroblastic nature is shown by the following evidence. Sieve structures, helizitic structures and crenulated borders are common. All gradations in development of porphyroblasts may be seen.

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[3] Goodspeed, G. E., and Coombs, Howard, Quartz-diopside-garnet veinlets: *Am. Mineral.*, vol. **17**, pp. 554–561, 1932.

In the earliest stages of growth, some of the plagioclase porphyroblasts are anhedral, some are even amoeba-like in form, surrounding and including all other constituents. Some show a shadow-like enlargement starting from a clear feldspar nucleus and including the adjacent groundmass of the hornfels. One of the most bizarre forms of initial growth is the development of ring-like forms of clear unaltered plagioclase enclosing, or partially enclosing, the finer grained constituents of the hornfels or portions of the kaolinized groundmass. On casual inspection some of these ring-like forms might be explained by differential alterations, but the identical nature of the material enclosed by the feldspar with that of the groundmass and thin extensions of clear feldspar into the groundmass precludes this possibility.

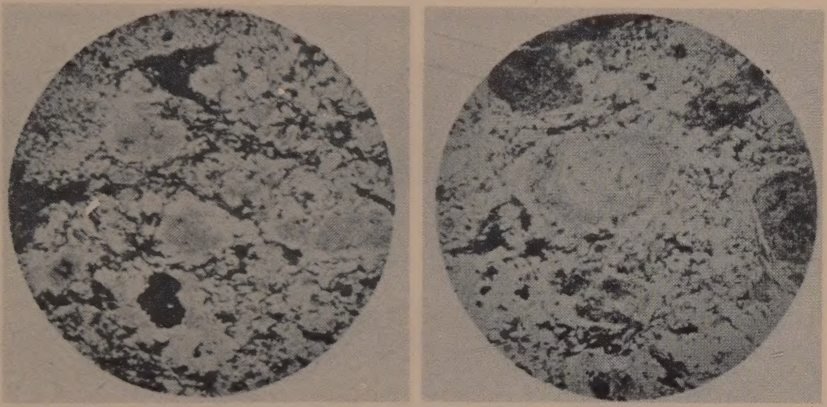

Fig. 2 Fig. 3

Plagioclase showing initial ring-like forms surrounding the groundmass. These initial porphyroblasts shown in this photomicrograph are ½ mm. in size.

The ring-like forms show slight variations in sodic and calcic content as is indicated by the variation in the extinction angle. In some the inner portion of the ring is more calcic than the outer portion, in others the outer portion of the ring-like crystal is more calcic. Some of the plagioclase porphyroblasts are similar to quartz porphyroblasts in that they are hardly discernible in plane light, although easily seen in crossed nicols.

Another point of similarity to the quartz porphyroblasts is the relationship of some of the porphyroblasts to ill defined spots or segregations of feldspathic material. One side of a spot may show a vague crystal outline, while another side has an irregular gradational contact with the groundmass. As might be expected, the stages of early crystalloblastic development are characterized by abundant inclusions. Even in these stages some crystals show Carlsbad and albite twinning, a feature which is similar to the twinning of cordierite in early stages. If crystallization proceeds from a center, these inclusions are forced to the periphery of the crystal, and then the porphyroblast tends to become free of inclusions.

Two or more plagioclase porphyroblasts may be grouped together, and for such groups it is proposed to use the term *glomeroblastic*, or if porphyroblasts of different minerals such as plagioclase and hornblende form the group, the term *cumuloblastic*. In some glomeroblastic groups the outlines of each crystal are traced by lines of inclusions forced out from the growing crystals. However, as these groups develop there is a tendency for the individual plagioclase crystals to coalesce and to form one individual. Both the outline and the internal structure of such crystals clearly reflect their mode of origin. In outline, sharp reentrant angles may be the result of the irregular growing together of several individuals. The original difference in composition in these crystals, as evidenced in zonal structure, may persist in the larger compound crystal giving rise to a very complex porphyroblast.

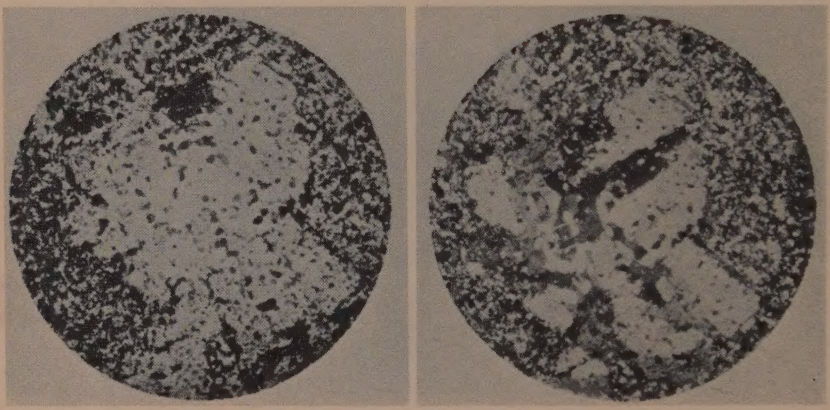

Fig. 4. Nicols not crossed. Fig. 5. Crossed nicols.

Photomicrographs showing the development of glomeroblastic aggregates 2 mm. in size.

The association of kaolinitic material with some plagioclase porphyroblasts may persist throughout their development while others are clear even in the initial stages. It seems apparent that turbidity is in part dependent upon the size of the included material, and the sections seem to show that this included material may have been some of the original finest constituents of the rock, or may have been formed by hydrothermal alteration just prior to the formation of the porphyroblast, or perhaps contemporaneously with its development. Upon further growth the plagioclase porphyroblasts became subhedral with the kaolinitic material evenly distributed throughout the crystals. Then in later stages the turbid kaolinitic material appears to be segregated usually in the central portions of the crystals while in the last stages it is irregularly distributed or segregated along twinning planes.

The segregation of kaolinitic material may be analogous to the movement of inclusions by crystallization pressure.[4] The distribution of included material may be in part controlled by the initial form of the feldspar porphyroblast. In the growth of a ring-like form it would be reasonable to expect a tendency for the surrounded material to become concentrated in the center of the crystal. In the other forms a centrifugal rather than a centripetal direction of movement of inclusions would occur. Kaolinitic material thus associated with plagioclase porphyroblasts bears some resemblance to the product of subsequent hydrothermal alteration, but may be differentiated from it by careful petrographic study. Subsequent alteration material usually occurs as an infiltration along cleavage cracks of originally clear crystals or in traversing veinlets. This material is commonly associated with sericite, while the kaolinitic material which has accumulated during the crystallization of the feldspars is much finer in grain and more homogeneous. Kaolinitic material of both these modes of origin is quite distinct from that due to surface weathering. Many of the sections studied were taken from mine workings hundreds of feet below the surface.

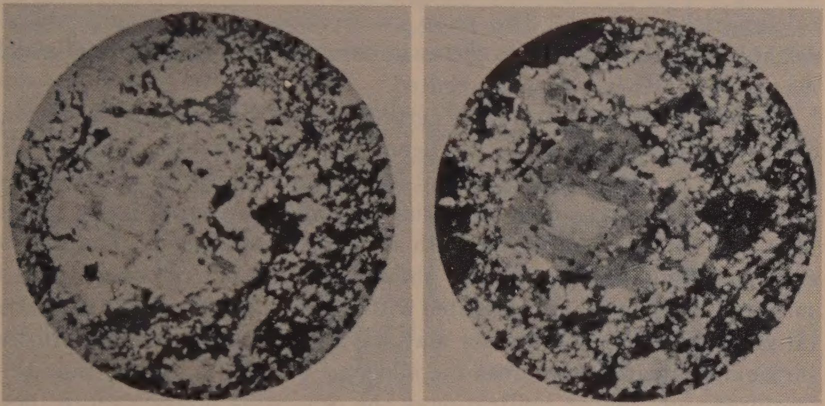

Fig. 6. Nicols not crossed. Fig. 7. Crossed nicols.
Coalescing of several smaller individuals to form a plagioclase porphyroblast, 1 mm. in size.

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[4] Harker, A., *Metamorphism*, Methuen & Co., London, 1932.

In many sections, plagioclase porphyroblasts appear to have developed sporadically without any structural control. In others they seem to be genetically associated with small feldspar veinlets. The plagioclase in these veinlets is usually sodic in composition and the crystals commonly show random orientations in the veinlets. Plagioclase porphyroblasts extend from these veinlets into the groundmass of the hornfels. These sections suggest that hot aqueous solutions, probably alkaline in character, were one of the important activating agents in the feldspathization of the hornfels. During the crystalloblastic development of the plagioclase, varying amount of calcium might be derived by the replacement of calcium-rich materials. The more calcic zones of the porphyroblasts might be explained as due to the assimilation of included material which may have previously been segregated.

Recent petrographic studies of certain rocks of the Cascade Mountains of Washington reveal some excellent examples of porphyroblastic development of plagioclase crystals.[5] Transitional facies of an indurated sandy shale into an igneous-appearing rock afford an opportunity to contrast and compare authigenic with allogenic constituents. The plagioclase porphyroblasts commonly show a gradational relationship with surrounding material, as contrasted with the even boundaries of the detrital grains. The porphyroblasts may have hair line extensions into the surrounding material whereas the allogenic grains are usually minutely fractured and show an infiltration of the cementing materials into these fractures. In these rocks the feldspar porphyroblasts may be euhedral and usually exhibit an even distribution of turbidity in contrast to the clearness of the allogenic grains even of very small size. This turbidity is probably due in part to the inclusion of material and in part to the development of kaolinitic material incident to the formation of the feldspar.

The recognition of porphyroblastic development is one of the essential points of petrogenetic significance in the consideration of igneous-appearing rocks which have apparently been formed by recrystallization-replacement incident to additive hydrothermal alteration.[6] Doris L. Reynolds has recently pointed out that an igneous appearance both in hand specimen and thin section does not constitute evidence that it has crystallized from a magma.[7] These studies of porphyroblasts show that many features such as zoning, complex twinning or selective "alteration" are not necessarily limited to the crystallization of magmas and lavas.

[5] Goodspeed, G. E., and Coombs, Howard A., Replacement breccias of the lower Keechelus: *Am. Jour. Sci.*, vol. **34**, pp. 12–23, 1937.

[6] Goodspeed, G. E., Small granodioritic blocks formed by additive metamorphism: *Journal Geology*, vol. **45**, pp. 741–762, 1937.

[7] Reynolds, Doris L., Demonstrations in petrogenesis from Kiloran Bay, Colonsay. I. The transfusion of quartzite: *Mineral. Mag.*, December, **1936**.

THE UNIT CELL AND SPACE GROUP OF TOURMALINE (AN EXAMPLE OF THE INSPECTIVE EQUI-INCLINATION TREATMENT OF TRIGONAL CRYSTALS)

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Abstract

The inspective equi-inclination treatment of hexagonal crystals in general is outlined. The lattice type may be determined with great ease merely by inspecting an appropriate n-level equi-inclination photograph. The reciprocal relations in the hexagonal system are also discussed. These are vital to an accurate unit cell determination and have not previously been discussed in this connection.

Two previous investigations have assigned tourmaline to space groups based upon a hexagonal lattice. This equi-inclination study plainly shows that it is based rather upon a rhombohedral lattice. The space group is unequivocally determined. The cell data for tourmaline from the Etta Mine, South Dakota, are as follows:

Diffraction symbol: 32/m R3 – –
Lattice: rhombohedral
Crystal class: C_{3v}
Space group: C_{3v}^5, R3m

Cell dimensions:	rhombohedral	referred to simplest hexagonal cell
	$a=9.500$ Å	$A=15.928$Å
	$\alpha=66°05'$	$C=7.151$
		$C/A=0.4490$
Formula weights of $\left\|\begin{matrix}\mathrm{Na}\\\mathrm{Ca}\end{matrix}\right\|\mathrm{R}_3\left\|\begin{matrix}\mathrm{Al}\\\mathrm{Fe}\end{matrix}\right\|_6\mathrm{B}_3\mathrm{Si}_6\mathrm{O}_{27}\left\|\begin{matrix}\mathrm{O}\\\mathrm{OH}\\\mathrm{F}\end{matrix}\right\|_4$ per cell:	1	3

Introduction

The unit cell and space group of tourmaline were first investigated by Miss Kulaszewski,[1] who based her studies mainly on Laue photographs made from thin slips cut parallel to (0001), $(10\bar{1}1)$, $(50\bar{5}2)$, $(01\bar{1}1)$, $(10\bar{1}0)$, and $(11\bar{2}0)$. These photographs were supplemented by oscillation spectrograms from these same slips, made with MoK radiation. She gives the following cell dimensions, referred to hexagonal axes, for clear rose-red tourmaline from Pennig, Saxony:

$$a = 16.23\text{Å}$$
$$c = 7.26$$

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[1] Kulaszewski, Charlotte, Über die Kristallstruktur des Turmalins: *Abhandl. math-phys. Kl. Sächn. Akad. Wissen.*, vol. **38**, 1921, included in Rinne, Friedrich: *Röntgenographische Feinbaustudien*, **4**, pp. 83–117.

Miss Kulaszewski's indexing of reflections (a monumental undertaking compared with the ease of attaining the required information by the inspective equi-inclination method) shows fulfillment of the analytical condition for the rhombohedral lattice,

$$\frac{h-i-l}{3} = \text{an integer},$$

by only 41% of the indices of reflections recorded from spectrograph photographs and by only 48.5% of those recorded from the Laue photographs. She accordingly selected the hexagonal lattice as the correct one for tourmaline. On the basis of reflection data, she assigned this mineral to either space group C_{3v}^1 or C_{3v}^2, between which it was impossible to distinguish.

These results were confirmed by Machatschki,[2] who employed the rotation method and the spectrometer method. Molybdenum radiation was used with the latter technique but no statement of the radiation used with the rotation method is given. He records the following axial data:

	Black tourmaline, Grundesund, Söndeled, Norway.	Pale red alkaline-earth tourmaline, San Diego, California.	Pale red tourmaline, Pala, California.
$a=$	16.02 Å	15.81 Å	15.87 Å
$c=$	7.22	7.10	7.13

Machatschki agrees with Miss Kulaszewski in finding many reflections eliminating a rhombohedral lattice, but with the proviso that the indexing of the reflections is somewhat uncertain due to the extreme length of the a-axis. The hexagonal cell contains 3 formula weights of $XY_9B_3Si_6H_xO_{31}$. Space groups C_{3v}^3 and C_{3v}^4 are eliminated on the basis of the appearance of odd orders of the basal reflection. Since the crystal class C_{3v} only has the six space groups $C_{3v}^{1,2,3,4,5,6}$, the last two of which are based upon a rhombohedral lattice, Machatschki implicitly agrees with Kulaszewski in assigning tourmaline to the two uneliminated hexagonal space groups C_{3v}^1 or C_{3v}^2, with the proviso mentioned.

Dr. J. D. H. Donnay called the attention of one of the writers to the fact that while the x-ray investigations of tourmaline had apparently assigned the crystal to a hexagonal lattice, the surface development points to a rhombohedral lattice, and he suggested that this discrepancy be investigated here by the equi-inclination[3,4,5] Weissenberg method. A reinvestigation of the unit cell and space group of tourmaline was accordingly undertaken. Since hexagonal crystals have not been previously treated by the inspective method,[4] this investigation constitutes a type case for the determination of the cell characteristics of crystals of this system without indexing procedure.

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[2] Machatschki, Felix, Die Formeleinheit des Turmalins: *Zeits. Krist.*, (A) vol. **70**, pp. 224–228, 1929.

[3] Buerger, M. J., The Weissenberg reciprocal lattice projection and the technique of interpreting Weissenberg photographs: *Zeits. Krist.*, (A) vol. **88**, pp. 356–380, 1934.

MATERIAL

The writers are indebted to Dr. Harry Berman of Harvard University for the gift of a number of suitable tourmaline crystals from the Etta Mine, South Dakota. This material consists of small crystals, less than 1 mm. long, and of about $\frac{1}{4}$ mm. in cross sectional diameter. The habit tends towards hexagonal prisms, without well-developed terminal faces. The refractive indices are as follows:

$$\omega = 1.658 \pm .002$$

$$\epsilon = 1.633 \pm .002$$

$$\omega - \epsilon = .025$$

While neither density nor analysis is available for this material, a density of 3.09 is suggested by a comparison of these optical properties with those compiled by Larsen and Berman.[6]

METHOD

The general methods have already been described.[3 4,5] Unfiltered copper radiation from a Hadding *x*-ray tube was employed.

THE CRYSTAL CLASS

The *c*-axis, 0-layer equi-inclination photograph displays the plane symmetry[4] C_{6l}, while the *n*-level photographs all display the plane symmetry C_{3l}. 0-layer photographs about each of the two possible hexagonal *a*-axes display the plane symmetries C_{2l} and C_2, respectively. These data fix the centro-symmetrical point-group as D_{3d}. These *x*-ray data permit the symmetry of tourmaline to be either C_{3v}, D_3, or D_{3d}. The absence of two-fold axes in the morphological development and other physical properties of tourmaline crystals definitely fixes the correct crystal class as C_{3v}.

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[4] Buerger, M. J., The application of plane groups to the interpretation of Weissenberg photographs: *Zeits. Krist.*, (A) vol. **91**, pp. 255–289, 1935.

[5] Buerger, M. J., An apparatus for conveniently taking equi-inclination Weissenberg photographs: *Zeits. Krist.*, (A) vol. **94**, pp. 87–99, 1936.

[6] Larsen, Esper S., and Berman, Harry, The microscopic determination of the nonopaque minerals: *U. S. Geological Survey, Bull.* **848**, p. 248, 1934.

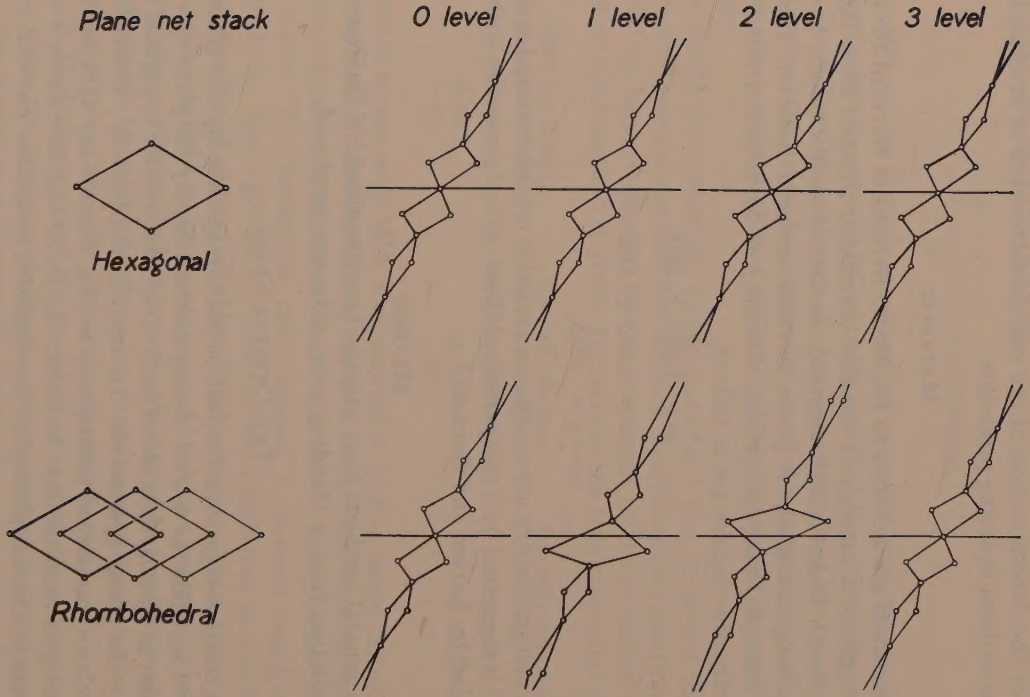
Plane net stack
0 level
1 level
2 level
3 level
Hexagonal
Rhombohedral

FIG. 1

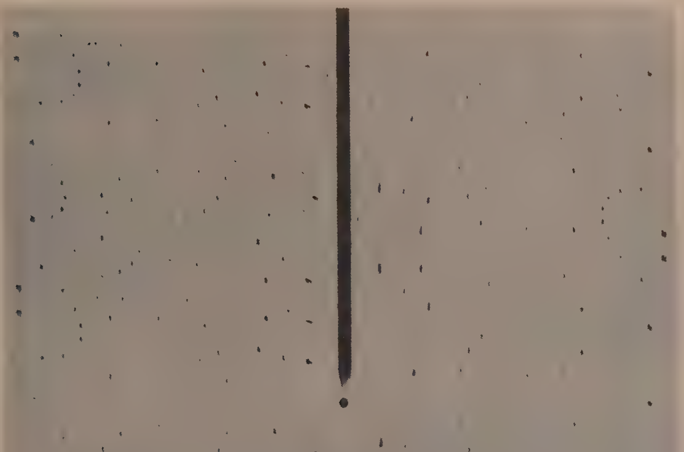

Fig. 4

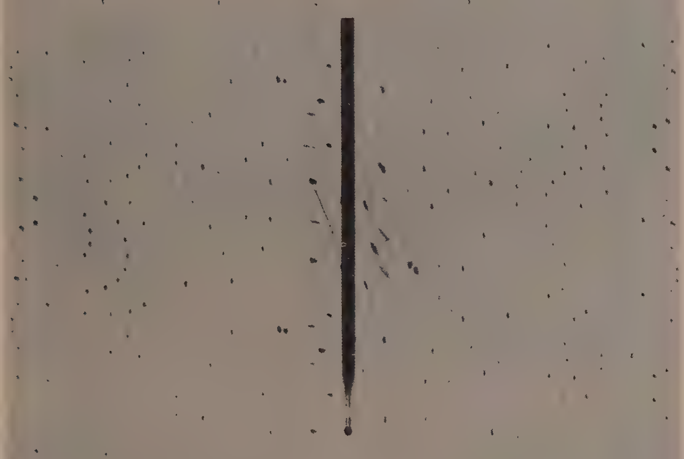

Fig. 3

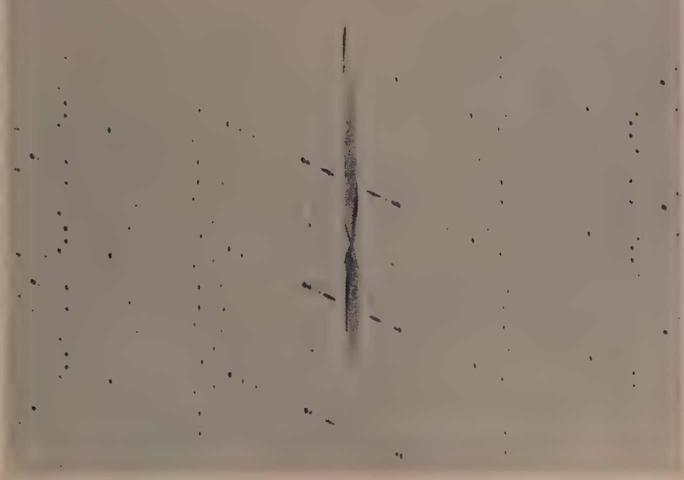

Fig. 2

THE SPACE LATTICE TYPE

A *c*-axis rotation photograph provides a rough estimate of the identity period along this axis, which in the case of the Etta tourmaline proved to be about 7.03 Å long. With this unrefined value, the equi-inclination settings and screen settings may be found.[5] A series of equi-inclination photographs for rotations about the *c*-axis permit one to resolve the reciprocal lattice into stacks of plane reciprocal lattices normal to the *c*-axis.[4] The analysis of this stacking unequivocally fixes the space lattice type. Both the hexagonal and rhombohedral lattices consist of stacks of equilateral triangular nets normal to the *c*-axis. In the case of the hexagonal lattice, the nets project on a plane parallel with the net plane in exactly superposed position, Fig. 1. In the case of the rhombohedral lattice they project in such a way as to be displaced by $\frac{1}{3}$ of a long mesh-diagonal for each succeeding layer. The equi-inclination Weissenberg projections of these layer sequences are unique, and characteristic portions are shown in Fig. 1. The displacement of the cells in the rhombohedral case is along one of the two nonequivalent position-symmetry lines of the photograph of the zero layer, or along the one set of unique position-symmetry lines of the *n*-layers. Figure 1 illustrates the point (reflection) environment of this line for the hexagonal and rhombohedral cases.

In Figs. 2, 3 and 4 are illustrated the equi-inclination photographs for the *c*-axis rotation in the case of tourmaline. The conditions plainly correspond with those illustrated for the rhombohedral lattice in Fig. 1. Tourmaline is accordingly based upon a rhombohedral, not a hexagonal lattice.*

THE SPACE GROUP

There are only two possible space groups for a crystal having the point group symmetry C_{3v} and based upon a rhombohedral lattice, namely C_{3v}^5 and C_{3v}^6. The differences between these, and the criteria to be sought in distinguishing them, are plainly indicated by their orientation symbols *R3m* and *R3c* respectively. In the first case the vertical symmetry planes appear as mirror planes, in the second case, they appear with glide component $c/2$. To distinguish between them it is merely necessary to investigate the character of the symmetry plane, which is done by comparing the 0- and *n*-level reciprocal lattice planes parallel with it. If these have identical translations, a mirror plane is indicated, while if the *c* translation is doubled on the 0-level, a glide plane with glide component $c/2$ is indicated.

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* Since this conclusion was at variance with earlier results, we also took the trouble to reconstruct[3] the reciprocal lattice for a 180° ω range for the 0, 1, 2, and 3 levels. The reciprocal lattice so obtained confirms the conclusion that the direct lattice of tourmaline is rhombohedral.

In the case of tourmaline, the former condition proves to be the case, which unequivocally fixes the space group for tourmaline as C_{3v}^5, *R3m*.

RECIPROCAL RELATIONS IN THE HEXAGONAL SYSTEM

Cell dimensions of rhombohedral crystals are conveniently derived by first referring the crystal to hexagonal coordinates and then transforming to rhombohedral coordinates. A knowledge of the relations between reciprocal and direct lattices is of fundamental importance in the determination of the dimensions of the direct lattice. These relations have been discussed from this viewpoint for all important cases[7] except the hexagonal ones.

The reciprocal relations for the hexagonal system are illustrated in Fig. 5. It will be observed that the reciprocal of a hexagonal lattice is another hexagonal lattice whose orientation is rotated 30° from that of the first. The reciprocal of a hexagonal coordinate system to which a rhombohedral crystal has been referred, however, is another hexagonal coordinate system of identical orientation. This is to be expected because the reciprocal of a rhombohedral lattice is another rhombohedral lattice of different dimensions but identical orientation.

The determination of the length of a direct cell axis consists of:

(1) Measurements of the film equivalents of one or more reciprocal axes.
(2) The calculation of the actual reciprocal axes from these measurements.
(3) The transformation of these reciprocal axes to the corresponding direct axes.

In the case of the determination of the *a* axes of hexagonal crystals, this consists of the measurements of the *x* values of the spots along either one of the two position symmetry lines of the equator photograph for the *c* axis rotation. Either the long diagonal identity period or the short diagonal identity period along the diamond reciprocal cell may be so measured. The resulting transformation to direct cell axes from one of these reciprocal measurements is indicated in Fig. 5.

In the case of the determination of the *c* axis by this general method, the following points should be remembered. The equator photograph of any zone containing the basal pinacoid may be used. In rhombohedral crystals, only the orders of (0001) divisible by 3 can appear as reflections due to the rhombohedral centering (Fig. 7), and, if the possible vertical symmetry plane is a glide plane, only orders of (0001) divisible by 6 appear. Missing equatorial spectra also occur in the hexagonal crystals due to space group symmetry operations.

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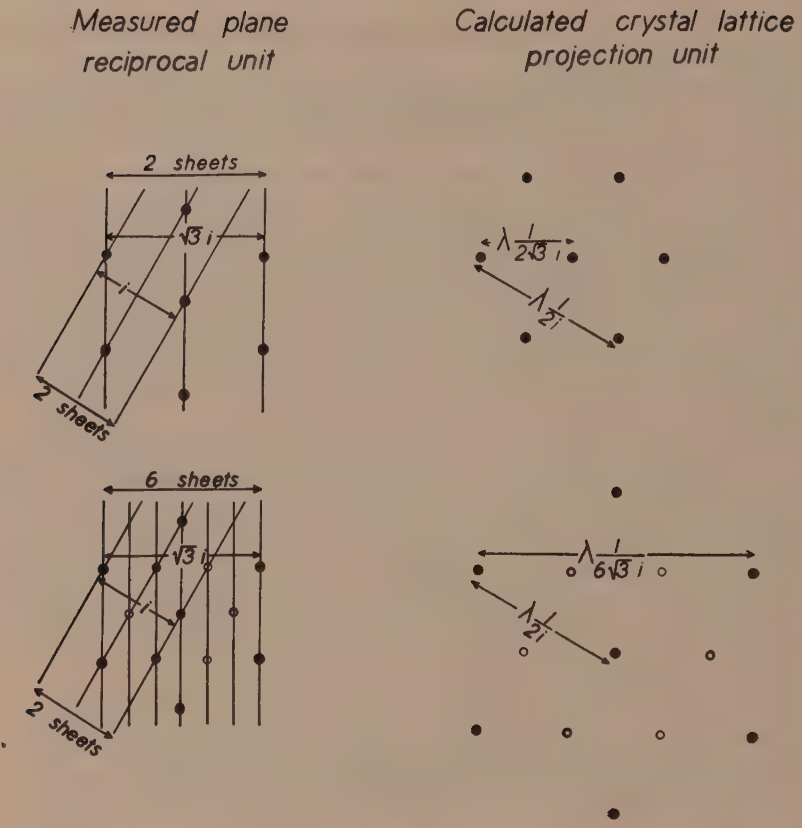
[7] Reference 4, pages 276–283.



Measured plane reciprocal unit

Calculated crystal lattice projection unit

FIG. 5

REFINING OF LATTICE DIMENSIONS

In another place, one of the writers has called attention[8] to the possibility of refining lattice dimensions derived from measurements made on photographs taken with a single crystal, by means of the method which Bradley and Jay[9] applied to powder photographs with great success. The writers give examples of this technique applied to the refining of the lattice dimensions of the Etta tourmaline. Measurements were made of the film equivalent of the identity period along the short diagonal of the reciprocal lattice. These measurements transform to the direct hexagonal axis with the aid of the relation:[8]

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[8] Buerger M. J., The x-ray determination of lattice constants and axial ratios of crystals belonging to the oblique systems: *Am. Mineral.*, vol. **22,** pp. 424–425, 1937.

[9] Bradley, A. J., and Jay, A. H., A method for deducing accurate values of the lattice spacings from x-ray powder photographs taken by the Debye-Scherrer method: *Proc. Phys. Soc.*, vol. **44,** pp. 563–579, 1932.

TABLE 1. COMPUTATION OF APPARENT LENGTH OF THE HEXAGONAL A-AXIS, FOR USE IN PLOTTING FIG. 6

Order	20	20	22	20	18	16	16	14
Radiation	CuKα_2	CuKα_1	CuKβ_1	CuKβ_1	CuK$\alpha_1+\alpha_2$	CuK$\alpha_1+\alpha_2$	CuKβ_1	CuK$\alpha_1+\alpha_2$
λ	1.54123Å	1.53739Å	1.38935Å	1.38935Å	1.53931Å	1.53931Å	1.38935Å	1.53931Å
Film reading, x_2	159.91 mm.	159.34 mm.	158.18 mm.	145.49 mm.	145.06 mm.	135.40 mm.	129.07 mm.	127.40 mm.
Film reading, x_1	9.17	9.65	10.86	23.72	24.01	33.81	40.26	41.95
$2x(=x_2+x_1)$	150.74	149.69	147.32	121.77	121.05	101.59	88.81	85.45
x	75.37	74.845	73.66	60.885	60.525	50.795	44.405	42.725
$\theta(=x+0.001x)$	75.445°	74.919°	73.733°	60.945°	60.585°	50.845°	44.449°	42.767°
θ	75°27′	74°55′	73°44′	60°57′	60°35′	50°51′	44°27′	42°46′
Log $(n/2)$	1.00000	1.00000	1.04139	1.00000	0.95424	0.90309	0.90309	0.84510
Log λ	0.18786	0.18678	0.14281	0.14281	0.18733	0.18733	0.14281	0.18733
Log $(n/2\ \lambda)$	1.18786	1.18678	1.18420	1.14281	1.14157	1.09042	1.04590	1.03243
Log sin θ	9.98584-10	9.98477-10	9.98226-10	9.94161-10	9.94005-10	9.88958-10	9.84528-10	9.83188-10
Log d	1.20202	1.20201	1.20194	1.20120	1.20152	1.20084	1.20062	1.20055
d	15.922Å	15.922Å	15.920Å	15.892Å	15.903Å	15.880Å	15.872Å	15.867Å
$\cos^2\theta$	0.0631	0.0677	0.0785	0.2355	0.2415	0.401	0.509	0.538

$$A, C = \frac{n\lambda}{2 \sin \theta} = \frac{n\lambda}{2 \sin \left(\frac{x}{2} \cdot \frac{360}{2\pi r_F} \right)}.$$

These calculations are conveniently arranged in tabular form as shown in Table 1. The plotting of the drift of the observed lattice constant against the film position of the spot, in the form of $\cos^2 \theta$, is shown in Fig. 6. This procedure leads to the following refined cell dimensions for the Etta tourmaline, referred to a hexagonal frame:

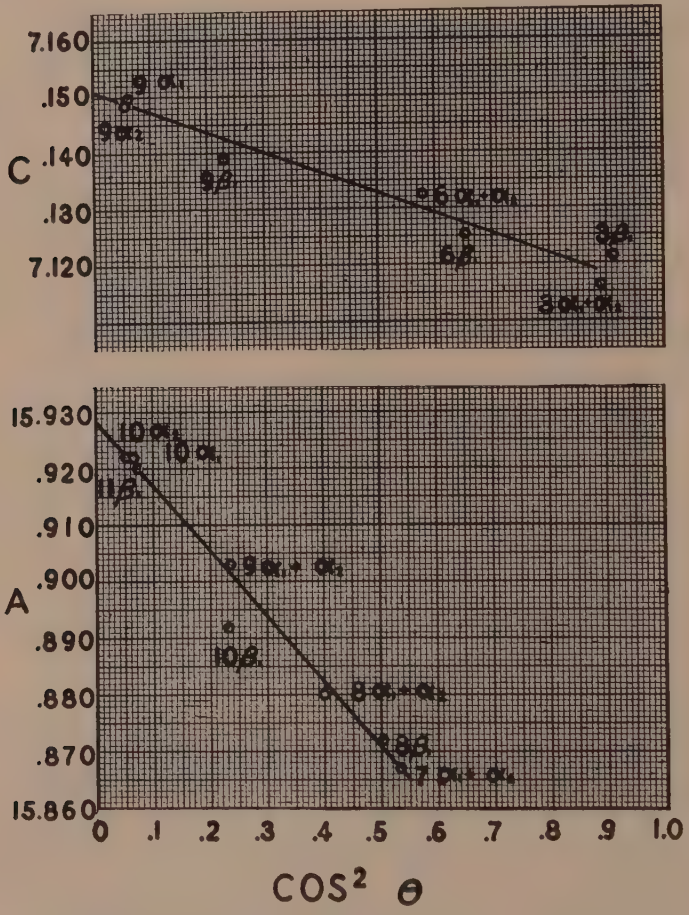
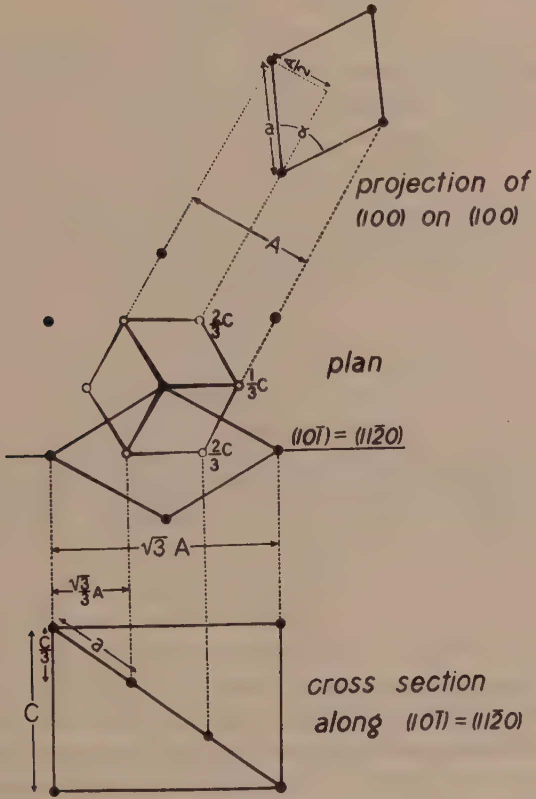


Fig. 6

$$A = 15.928\text{Å}$$
$$C = 7.151$$
$$\frac{C}{A} = 0.4490.$$

TRANSFORMATION FROM HEXAGONAL COORDINATES TO RHOMBOHEDRAL COORDINATES

In Fig. 7 the projection of part of a rhombohedral lattice upon (111) = (0001) and a section along $(10\bar{1}) = (11\bar{2}0)$ are shown. From these it is apparent that a crystal based upon a rhombohedral lattice can be referred to a cell having hexagonal identity periods. If the hexagonal



a
α
A/2
A
projection of (100) on (100)
2/3 c
1/3 c
plan
(10$\bar{1}$) = (11$\bar{2}$0)
2/3 c
√3 A
√3/3 A
C/3
a
C
cross section along (10$\bar{1}$) = (11$\bar{2}$0)

FIG. 7

identity periods are designated A and C, it is evident from Fig. 7 that the rhombohedral identity period is related to it as follows:

$$a^2 = \left(\frac{\sqrt{3}A}{3}\right)^2 + \left(\frac{C}{3}\right)^2$$

from which,

$$a = \tfrac{1}{3}\sqrt{3A^2 + C^2}. \tag{1}$$

Figure 7 also shows one of the rhombohedral faces of the rhombohedral unit cell projected on a plane parallel with itself. From this projection it can be seen that the rhombohedral interaxial angle, α, may be derived from the following relation:

$$\sin\frac{\alpha}{2}=\frac{A/2}{a}. \qquad (2)$$

Substituting in (2), the value of a given by (1) yields the useful relation:

$$\sin\frac{\alpha}{2}=\frac{6A}{\sqrt{3A^2+C^2}}. \qquad (3)$$

Another form of this relation may be obtained by substituting the value of $\sin \alpha/2$ given by (3) in the trigonometric identity:

$$2\sin^2\frac{\alpha}{2}=1-\cos\alpha. \qquad (4)$$

This gives the rhombohedral interaxial angle in a form dependent only on the hexagonal axial ratio, C/A, thus:

$$\alpha=\cos^{-1}\left[\frac{2\left(\frac{C}{A}\right)^2-3}{2\left(\frac{C}{A}\right)^2+6}\right] \qquad (5)$$

When these transformations have been applied to the hexagonal dimensions of the Etta tourmaline cell, the following rhombohedral cell dimensions result:

$$a = 9.500 \text{ Å}$$
$$\alpha = 66°05'$$

Discussion

While the cell dimensions given here are comparable with those of earlier investigators, the other results differ radically in referring tourmaline to a rhombohedral lattice rather than to a hexagonal lattice. This, of course, completely changes the space group of tourmaline and has a radical effect on any attempt to derive the crystal structure of tourmaline. The writers are continuing this aspect of the investigation.

It is believed that the earlier investigations went astray because their methods (Laue and rotation) were not sufficiently powerful to resolve reflections for a crystal with such a large A axis (about 16 Å). The short wavelengths of tungsten and molybdenum radiation employed contributed to the difficulty of resolving reflections, but it is doubtful whether longer radiation would have helped greatly with the rotation method. The long axis is, however, ideally handled with the equi-inclination Weissenberg method.

PENCATITE FROM THE ORGAN MOUNTAINS, NEW MEXICO

WALTER F. HUNT, *University of Michigan, Ann Arbor, Michigan,*
AND
GEORGE T. FAUST, *Rutgers University, New Brunswick, New Jersey.*

INTRODUCTION

The geological process known as dolomitization, or the conversion of limestone to dolomite, is recognized as of common occurrence and some of the methods by which this change is thought to have been brought about are fairly well understood. But, the reversal of this process, namely the dedolomitization of dolomites and magnesium limestones by thermal metamorphism with the formation of periclase and other accompanying minerals is quite uncommon, judging from the comparatively few occurrences, especially in the United States, reported thus far in the literature.[1]

In November 1931 several rock specimens were received from a prospector in El Paso, Texas, who sent them in for identification. A very brief statement accompanied the shipment to the effect that the specimens were collected from the south end of the Organ Mountains, New Mexico, about eighteen miles north of the Texas border. The following March a brief description was given before the Michigan Academy of Science, Arts and Letters.[2] Since then additional microscopic data have been secured, the rock has been analyzed, and a recent Bulletin on the Geology of the Organ Mountains issued by the New Mexico School of Mines[3] now makes it possible to establish the locality from which the specimens came, if not definitely, still within narrow limits.

In brief, according to Dunham[4] dolomites of Lower Paleozoic age outcrop at the southern end of the Organ Mountains and have been invaded by a batholith of quartz monzonite. Large xenoliths of dolomite found in the quartz monzonite in the vicinity of South Canyon have been completely altered, also at Target Range (head of Target Range Canyon) silication of impure beds extends to 400 feet while recrystallization has been traced for a distance of over 2500 ft. from the igneous intrusion (Fig. 1).

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[1] A. F. Rogers has reported previously on four other occurrences in the United States: at Crestmore and Riverside, California; at the Mountain Lake mine, about twenty-five miles south east of Salt Lake City, Utah; and in the Phillipsburg quadrangle, Montana. *Am. Jour. Sci.* vol. **46**, pp. 581–586, 1918; *Am. Mineral.*, vol. **14**, pp. 462–469, 1929.

[2] Hunt, W. F., *Proc. Mich. Acad. Sci., Arts, and Letters*, 34th and 35th Annual Reports, Paper No. 15, Section of Geology & Mineralogy, **1932.**

[3] *Bull.* **11**, *New Mexico School of Mines*, 1935. The Geology of the Organ Mountains by Kingsley Charles Dunham. Also *Am. Mineral.*, vol. **21**, pp. 312–318, 1936.

[4] *Idem.*, p. 93.

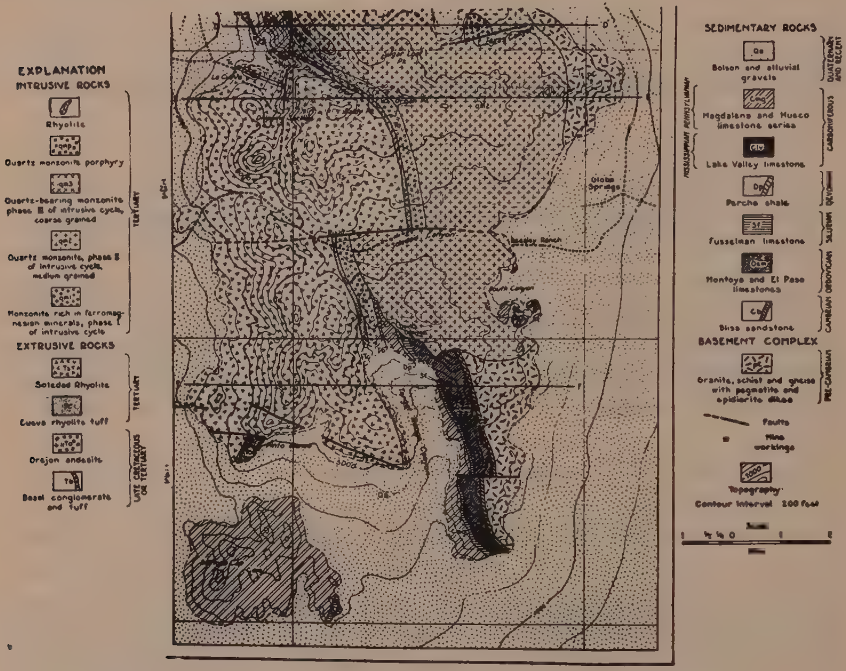
EXPLANATION
INTRUSIVE ROCKS
Rhyolite
Quartz monzonite porphyry
Quartz-bearing monzonite phase III of intrusive cycle, coarse grained
Quartz monzonite, phase II of intrusive cycle, medium grained
Monzonite rich in ferromagnesian minerals, phase I of intrusive cycle
TERTIARY
EXTRUSIVE ROCKS
Soledad Rhyolite
Cueva rhyolite tuff
TERTIARY
Orejon andesite
Basal conglomerate and tuff
LATE CRETACEOUS OR TERTIARY
SEDIMENTARY ROCKS
Qa
Bolson and alluvial gravels
QUATERNARY AND RECENT
Cmg
Magdalena and Hueco limestone series
Clv
Lake Valley limestone
CARBONIFEROUS
MISSISSIPPIAN PENNSYLVANIAN
Dp
Percha shale
DEVONIAN
Sf
Fusselman limestone
SILURIAN
Oem
Montoya and El Paso limestones
ORDOVICIAN
Cb
Bliss sandstone
CAMBRIAN
BASEMENT COMPLEX
Granite, schist and gneiss with pegmatite and epidiorite dikes
PRE-CAMBRIAN
Faults
Mine workings
1000
Topography
Contour interval 200 feet
1 ½ ¼ 0 1 2
Globe Springs
South Canyon
3000

FIG. 1. Geology of lower portions of the Organ Mountains, according to K. C. Dunham, *Bull.*. **11**, *New Mexico School of Mines*, showing invasion of dolomite by batholith of quartz monzonite.

As a result of this thermal treatment the dolomite has been changed in the following manner. The calcium carbonate portion has been recrystallized forming an interlocking mosaic of irregular grains which serve as a host for a number of other minerals. The magnesium carbonate component of the original dolomite is broken down to the oxide, periclase. This mineral is very unstable and has largely dissappeared as such from the rock. Most of the magnesium oxide has changed to the hydrated oxide, brucite, which in turn has altered, in part, to magnesite. Occasionally, however, fragments of unaltered isotropic periclase may still be observed either in the calcite, but more generally as a residual core in the brucite. This would seem to indicate that the hydrothermal solutions had been insufficient in amount to hydrate all the periclase.

A small amount of silica was either present in the original dolomite or was introduced by the solutions that brought about hydration as some of the magnesium has combined with it to form forsterite. This mineral in turn has likewise been hydrated, in part, producing the antigorite variety of serpentine. Other minerals present in still smaller amounts include pyrite, limonite and occasional small reddish-brown grains of rutile. No lime silicate minerals were observed in any of the slides examined.

Description of the Minerals

Megascopic

In general appearance the rock resembles a dull white marble. A freshly broken surface presents a granular texture and possesses a distinct white color. An alteration, noted on the surface of some of the specimens, consists of a white powdery substance, probably hydromagnesite. Distributed throughout the specimens are small, dull-white areas with circular or elliptical outlines which represent the mineral brucite, $Mg(OH)_2$. The exposed surface is somewhat pitted due to the leaching of this fairly soluble constituent. A few specks of pyrite and occasional brownish stains of iron oxide were also noted.

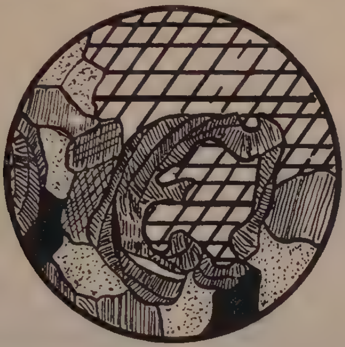

Fig. 2. The broad polysynthetic twinning lamellae of calcite are sometimes continuous through the elliptical patches of brucite. The remaining grains are dusty calcite with mosaic texture in various orientations.

Microscopic

An examination of six thin sections reveals a typically mosaic texture. The following minerals were identified.

Calcite. This mineral is by far the most important constituent of the rock and constitutes, together with magnesite, about 70% of the entire area. The interlocking grains are quite irregular in outline and many possess a dusty appearance. Some of the larger grains are biaxial in character with a small axial angle. A number of grains exhibit two sets of broad polysynthetic twinning lamellae which intersect and give rise to rhombic outlines. The average size of the calcite grains as measured on one section was about 0.4 mm. The calcite serves as the host for the accessory minerals which include brucite, periclase and forsterite.

Figure 2, which represents a drawing of an observation under crossed nicols, shows that the twinning lamellae are sometimes continuous through the brucite. The twinning may have developed from strains resulting from the hydration of periclase to brucite, since this change involves an increase in volume of approximately 117%.

Brucite. This mineral constitutes, on an average, 26% of the area of the thin sections. It occurs in typically circular to elliptical aggregates. In plane polarized light the patches are colorless, and their complex, delicate foliated structure is revealed to best advantage under crossed nicols. Each circular area consists of a series of concentric swirls of fibrous or foliated aggregates. Some of the brucite masses enclose areas of calcite or small grains of unaltered isotropic periclase. (Figs. 3 and 4.)

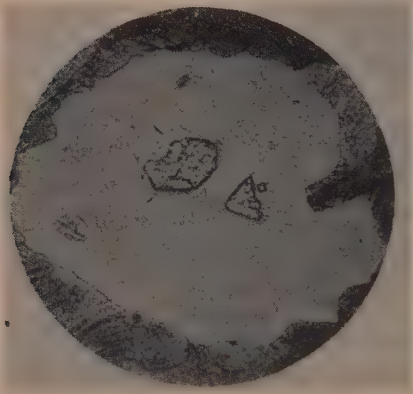

Fig. 3

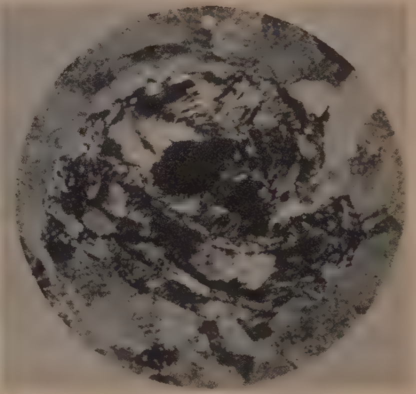

Fig. 4

Fig. 3. Brucite aggregate enclosing fragments of unaltered periclase. Plane polarized light. ×70. Note the high relief of the periclase.

Fig. 4. Same as Fig. 3 but with crossed nicols. Brucite occurring as a series of concentric swirls of foliated aggregates. The two black enclosed grains are isotropic periclase. ×70.

It would seem that the brucite masses, developed from the periclase through hydration, were not formed during a single operation; rather, the reaction proceeded in successive stages gradually eliminating the MgO, although in some instances a small residual grain or two still remains. Also, the direction and amount of water causing the hydration varied from time to time as the widths and number of concentric rims of brucite are not constant in any single area.

The average diameter of the brucite aggregates was found to be 0.98 mm., while the largest single area noted measured 1.48 mm. The optical properties were measured on fragments taken from the lenticular masses. The fragments are composed of bent foliae with wavy extinction and exhibit low yellow-gray anomalous interference colors. The indices were: $\omega = 1.565 \pm 0.002$; $\epsilon = 1.585 \pm 0.002$. Elongation (−). These values are slightly higher than those given by Larsen and Berman, but agree well with those reported by Watanabe and Rogers as shown in the accompanying table.

TABLE 1. OPTICAL PROPERTIES OF BRUCITE.

Observer	Hunt & Faust	Larsen & Berman[5]	Watanabe[6]	Watanabe[6]	Rogers[7]
Locality	Organ Mts., New Mexico	None given	Nantei, Japan	Keikansan, Japan	Riverside, California
ω	1.565 ±0.002	1.559	1.566 ±0.002	1.565 ±0.002	1.567 ±0.003
ϵ	1.585 ±0.002	1.580	1.584 ±0.002	1.584 ±0.002	1.583 ±0.003
$\epsilon - \omega$	0.020	0.021	0.018	0.019	0.016
Elongation	(−)		(−)	(−)	(−)

The higher values recorded by Watanabe, Rogers, and the writers may be due to the presence of a small amount of iron oxide in solid solution in the brucite, for in the literature two types of ferriferous brucites are mentioned. Nemalite is defined by Dana[8] as "a fibrous variety containing 4 to 5 per cent of iron protoxide." Berman[9] reports a nemalite from Quebec with negative elongation and $\epsilon = 1.586$, and containing 9 per cent FeO. The term ferrobrucite has also been applied to iron-bearing brucites.

Antigorite. This mineral has developed from the forsterite as remnants of former forsterite grains are often still observed. A noteworthy feature of this antigorite is the absence of any concentration of iron oxides within it. The antigorite is easily distinguished from the brucite under crossed nicols because of differences in structure, interference colors and type of extinction. The indices of refraction of brucite are also higher than those of antigorite and the Becke line test can be used to advantage. The average of a number of measurements revealed a grain size of about 0.10 mm. The interference colors are a very low blue-gray, almost isotropic.

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[5] Larsen, E. S., and Berman, H., *Bull.* **848,** *U. S. Geol. Survey,* p. 70, 1934.

[6] Watanabe, Takeo, *Jour. Fac. Sci. Hokkaido, Imperial Univ.,* Ser. 4, vol. **3**, No. 1, p. 55, 1935.

[7] Rogers, A. F., *Am. Jour. Sci.,* vol. **46,** p. 582, 1918.

[8] Dana, *System of Mineralogy,* 6th edition, p. 252.

[9] Berman, H., *Am. Mineral.,* vol. **17,** pp. 313–314, 1932.

Forsterite. The forsterite grains are distributed throughout the calcite and are occasionally enclosed in the brucite swirls. They reveal in various degrees the usual alteration to antigorite (Fig. 5). A grain size determination made on a number of fragments gave an average reading of 0.04 mm.

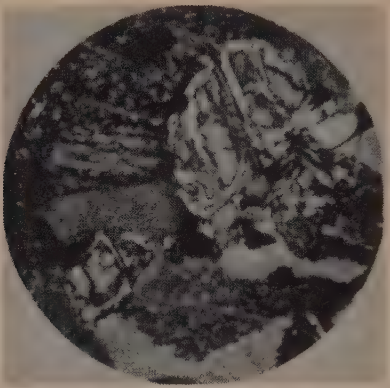

Fig. 5. Forsterite grains in upper right portion showing alteration to antigorite.

Periclase. This constituent is present as residual cores in some of the brucite aggregates and occasionally as unaltered grains in the calcite. It rarely occurs in the antigorite areas. The fragments in cross section often show square, rectangular or trigonal outlines. The average grain size is 0.07 mm. but there is considerable variation, from 0.02 to 0.16 mm.

Iron Oxides. These occur in irregular patches and veinlets, the borders of which are unmatched and are controlled principally by the contours of the brucite and calcite grains. Iron oxide flakes and stringers occasionally cut across the brucite swirls or calcite grains.

Rutile. Rutile was found very sparingly occurring in reddish-brown prismatic crystals or rounded grains in the calcite groundmass. The grains have an average size of 0.08 mm.

Pyrite. A few minute specks of pyrite were noted in the hand specimen, but no particles were encountered in the traverses with the recording micrometer.

Micrometric Measurements

A micrometric survey of three thin sections was made using the improved Wentworth recording micrometer described by Hunt.[10] As recommended by Larsen and Miller[11] the measurements were carried out by making fifteen traverses across the slide, one millimeter apart. A Leitz No 3X objective and No. III ocular were employed, giving a magnification of 82 diameters. The results are given in Table 2.

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[10] Hunt, W. F., *Am. Mineral.*, vol. **9**, pp. 190–194, 1924.

[11] Larsen, E. S., and Miller, F. S., *Am. Mineral.*, vol. **20**, pp. 260–274, 1935.

TABLE 2. AREAL ANALYSES.

Mineral	Section No. 1	Section No. 2	Section No. 3	Average
Brucite	27.5%	26.8%	23.8%	26.1%
Calcite (and Magnesite)	69.6	68.5	71.9	70.0
Antigorite	2.0	3.8	3.7	3.1
Forsterite	0.7	0.4	0.3	0.5
Periclase	0.1	0.3	0.2	0.2
Rutile (and iron oxides)	0.1	0.2	0.1	0.1
Totals	100.0	100.0	100.0	100.0
Aggregate units traversed	48,221	49,484	50,965	49,557
Distance traversed in mm.	241	247	255	244

CHEMICAL ANALYSES

QUALITATIVE

The rock powder effervesces freely with cold dilute HCl acid. Strong tests were obtained for both calcium and magnesium; also considerable water was evolved in a closed tube.

QUANTITATIVE

Carefully selected fresh fragments were broken up in a "Geophysical Laboratory mortar and pestle" and a 22-gram sample was prepared for the analysis. The powder was exposed to a magnet to make sure that no particles of the crushing apparatus were included.

The carbon dioxide was determined gravimetrically. To make sure that the absorption train was in proper condition, a check run on a pure sample of calcium carbonate was made before and after each carbon dioxide determination on the rock sample. This demonstrated the absence of leaks and the active character of the absorbent (ascarite). One gram samples of the rock were treated with sixty cc. of perchloric acid (1:5 dilution of 72 % strength) containing 0.5 gram of sodium chromate. The addition of sodium chromate to the perchloric acid solution oxidizes the sulphide to sulphuric acid, thus eliminating the use of a

$CuSO_4 \cdot 5\,H_2O$ tube to remove the H_2S otherwise generated in the reaction.[12] Two determinations gave values of 31.10 and 31.13% CO_2. The main analysis for SiO_2, R_2O_3 group, CaO and MgO was conducted according to standard methods. The water was determined by absorption in "dehydrite" (anhydrous $MgClO_4$). The results are recorded in Analysis 1, Table 3. For comparison, a partial analysis, Analysis 2, on material from Target Range Canyon, Organ Mountains, given in a report by Dunham[13] is likewise listed. The agreement of the main constituents in the two analyses is very close.

TABLE 3. CHEMICAL ANALYSES OF THE ROCK

	Analysis 1		Analysis 2
SiO_2	2.07		1.60
Al_2O_3	0.64		0.35
Fe_2O_3			0.73
MgO	23.48		23.01
CaO	34.62		34.04
H_2O	8.53	Ignition loss	40.27
CO_2	31.12		
MnO	tr.		
Total	100.46		100.00

Analyst: George T. Faust

Analyst: H. C. Lee

As a matter of interest, and as an aid in planning the analysis, a spectroscopic examination of two samples of the powder was kindly made by Dr. Kenneth B. Thomson, research spectroscopist in the department of physics. He reported as follows:

> "Main constituents: Mg, Ca, Si
> Minor constituent: Fe
> Traces: Mn, Sr, Al, Cu
>
> NOTES: Lead and nickel appear in one spectrum but not in the other and are almost certainly due to contamination from the arc holders. No lines due to titanium or vanadium were observed. Barium is there only as a small trace. The carbon band falls in the position of the most sensitive barium line."

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[12] Method suggested by Professor H. H. Willard of the Dept. of Chemistry in a personal communication.

[13] Dunham, K. C., *Bull.* 11, *New Mexico School of Mines,* The Geology of the Organ Mountains, p. 104, 1935.

CALCULATIONS

Using the average volumetric analysis and the following values for the specific gravities: calcite 2.72, brucite 2.40, antigorite 2.60, forsterite 3.21, periclase 3.6, rutile 4.2, iron oxide 3.8, the weight percentage was calculated and is given in column 1 of Table 4. In column 2 are the weight percentages by Dunham[14] on an unanalyzed brucite marble from South Cayon, Organ Mountains.

TABLE 4. WEIGHT PERCENTAGE CALCULATED FROM AREAL MEASUREMENTS

Mineral	1	2
Brucite	23.7	36.2
Calcite and magnesite	72.1	62.3
Antigorite	3.1	1.5
Forsterite	0.6	
Periclase	0.3	
Rutile and iron oxides	0.2	
Total	100.0	100.0

The chemical analysis was then recast in terms of mineral components in order to compare the results with the gravimetric micrometric measurements. In order to carry out this comparison the CaO was calculated to calcite and the remaining CO_2 was assigned to magnesite. The SiO_2 with the necessary amounts of MgO and H_2O were computed to antigorite. The remaining MgO and H_2O were present in the proper proportion to form brucite. The computations involved are shown in Table 5.

TABLE 5. RECALCULATION OF CHEMICAL ANALYSIS

Chemical Analysis (Minus Al_2O_3 and Fe_2O_3)		Recal. to 100%	Combining ratios	Calcite $CaO \cdot CO_2$	Magnesite $MgO \cdot CO_2$	Antigorite $3MgO \cdot 2SiO_2 \cdot 2H_2O$	Brucite $MgO \cdot H_2O$
SiO_2	2.07	2.07	.0344			.0344	
MgO	23.48	23.52	.5833		.0902	.0516	.4415
CaO	34.62	34.68	.6184	.6184			
H_2O	8.53	8.55	.4746			.0344	.4402
CO_2	31.12	31.18	.7086	.6184	.0902		
	99.82	100.00		Calcite 61.9%	Magnesite 7.6%	Antigorite 4.8%	Brucite 25.7%

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[14] Loc. cit., p. 103.

Table 6 shows the results of the comparison of recast chemical analysis with the gravimetric micrometric measurements. It will be noted that the deviation is in each case quite small, varying from less than 1% in the case of the antigorite-forsterite-periclase group to 2.0% in brucite.

TABLE 6. COMPARISON OF RECAST CHEMICAL ANALYSIS WITH THE GRAVIMETRIC MICROMETRIC MEASUREMENTS

Calculated from Analysis			Measured with Micrometer	
Calcite	61.9	69.5%	72.1%	
Magnesite	7.6			
Brucite	25.7		23.7	
Antigorite	4.8	4.8	3.1	4.0
Forsterite	0.0		0.6	
Periclase	0.0		0.3	

NOMENCLATURE

The question of the nomenclature of this rock can now be considered in the light of the preceding analyses. Two rock names appear in the literature for dedolomitized dolomites and magnesium limestones, pencatite and predazzite, depending upon the amounts of brucite and calcite developed, which in turn depend upon the magnesium and calcium contents of the original rock. Harker[15] has defined in a quantitative manner the meaning of the terms pencatite and predazzite as follows:

"It is most in accordance with the original usage to employ the name pencatite for an aggregate of calcite and brucite in equal molecular proportions, i.e. with the percentage composition of 63.3 calcite to 36.7 brucite, reserving the predazzite for varieties richer in calcite."

The rock here described contains 62% calcite and while the amount of brucite is less than that theoretically demanded, all of the magnesium was not converted to brucite as other magnesium minerals have formed instead, so that the term pencatite seems the more appropriate one to use.

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[15] Harker, A., The Tertiary igneous rocks of skye: *Mem. Geol. Surv. United Kingdom*, pp. 144–151, **1904**; Metamorphism, p. 77, **1932**.

CLASSIFICATION OF THE NATURAL SILICATES

PART II. COMPOSITION OF THE NATURAL SILICATES

CHARLES K. SWARTZ,
The Johns Hopkins University, Baltimore, Md.

(*Continued from page 1087*)

The following tables give the composition of the natural silicates thus far determined by x-ray investigations. The species are arranged according to the classification proposed in the preceding part of the discussion.

The complex silicates are indicated by printing their names in italics. The roman figures beneath the names indicate their constituent types, thus $\frac{\textit{Vesuvianite}}{\text{I–II}}$ signifies a complex silicate of types I and II. The complex silicates are placed in the table with the simplest type entering into the composition of each.

A few species have been included in the tables whose structures are not adequately known. Such species (or families) are indicated by an asterisk * following their names. The figures enclosed in brackets after the names refer to the literature citations at the end.

CLASSIFICATION OF THE NATURAL SILICATES

I. SiO_4 GROUPS UNCOMBINED. ORTHOSILICATES, R'_4SiO_4.

1. *Bivalent Silicates,* R''_2SiO_4.

a. Anhydrous.

1. Olivine family (1). Orthorhombic
   - a. Mg, Fe section
     - Fosterite Mg_2SiO_4
     - Olivine (1) $(Mg, Fe)_2SiO_4$
     - Fayalite Fe_2SiO_4
   - b. Ca section[1]
     - Monticellite (2) $CaMgSiO_4$
2. Phenacite family. Trigonal
   - Phenacite (3) Be_2SiO_4
   - Willemite (4) Zn_2SiO_4
   - Troostite $(Zn, Mn)_2SiO_4$

b. Hydrous.

1. Chondrodite series (5), $n\ Mg_2SiO_4+Mg(OH, F)_2$, n even monoclinic, n odd orthohombic
   - Norbergite (6) $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Orthorhombic

---

[1] A Mn, Fe section may, possibly, be added here. It embraces the minerals
Tephroite Mn_2SiO_4
Knebellite $(Fe, Mn)_2SiO_4$.

Chondrodite 2 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Monoclinic
Humite 3 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Orthorhombic
Clinohumite 4 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Monoclinic

2. Complex division
Bertrandite (7) $Be_2(BeOH)_2 \left| \begin{matrix} SiO_4. \\ SiO_3. \end{matrix} \right.$ Orthorhombic
I–III

2. *Trivalent Silicates*, $R'''_4(SiO_4)_3$.

a. Anhydrous.

1. Garnet family (8) $R''_3R'''_2(SiO_4)_3$. Isometric
2. Cyanite series (9) Al_2OSiO_4
   Sillimanite (10) Coordination $\frac{1}{2}Al=4$, $\frac{1}{2}Al=6$. Orthorhombic
   Andalusite (11) Coordination $\frac{1}{2}Al=5?$, $\frac{1}{2}Al=6$. Orthorhombic
   Cyanite (12) Coordination $Al=6$. Triclinic
3. Eulytite series $Bi_4(SiO_4)_3$
   Eulytite (13) Isometric
   Agricolite *Monoclinic
4. Complex division.
   Mullite (14)*[2] $(Al_2O)_8 \left| \begin{matrix} (SiO_4)_6 \\ Al_2O_7 \end{matrix} \right.$ Orthorhombic
   I–II

b. Hydrous.

1. Staurolite (15) 2 cyanite+$Fe(OH)_2$. Orthorhombic
2. Topaz (16) $Al_2(OH, F)_2SiO_4$. Orthorhombic
3. Euclase (17) $Al(BeOH)SiO_4$. Monoclinic
4. Complex division
   Vesuvianite (18) $Ca_{10}Al_4 \left| \begin{matrix} (SiO_4)_5 \\ (Si_2O_7)_2 \end{matrix} \right| \cdot 2Mg(OH)_2$. Tetragonal
   I–II

3. *Quadrivalent Silicates* $R^{IV}SiO_4$.

a. Anhydrous.

1. Zircon family $R^{IV}SiO_4$. Tetragonal
   Zircon (19) $ZrSiO_4$
   Thorite* $ThSiO_4$
2. Titanite (20) $Ca(TiO)SiO_4$. Monoclinic

II. SiO_4 GROUPS COMBINED BY ONE SOLID ANGLE. ORTHODISILICATES. $R'_6Si_2O_7$ .PAIRS

1. *Bivalent Silicates* $R''_3Si_2O_7$.

b. Hydrous.

Calamine (21) $Zn_2(ZnOH)_2Si_2O_7 \cdot H_2O$. Orthorhombic

2. *Trivalent Silicates*, $R'''_2Si_2O_7$.

a. Anhydrous.[3]

1. Thortveitite (22) $Sc_2Si_2O_7$. Monoclinic

---

[2] The empirical formula of mullite is $3Al_2O_3 \cdot 2SiO_2$. Taylor showed that the x-ray patterns of mullite and sillimanite are similar and suggests that their structures are analogous. He derives mullite from 8 molecules of sillimanite by removing one atom of O and replacing two Si by two Al. The result suggests a formula of the above type, but the true structure of mullite is unknown.

[3] For danburite see type V.

2. Aenigmatite (23)*[4] $X_4Y_{13}(Si_2O_7)_6$. X = (Na, Ca, K). Y = (Fe″, Ti, Fe‴, Mg, Al). Triclinic

3. *Bivalent to Quadrivalent Silicates.*

a. Anhydrous.

1. Melilite family (24)[5] $X_2Y(Si, Al)_2O_7$. X = (Ca, Na). Y = (Mg, Fe, Zn, Si, Al). Tetragonal
   - a. Bivalent section Ca$_2$(Mg, Zn)
     - Akermanite (24) $Ca_2MgSi_2O_7$
     - Hardystonite (25) $Ca_2ZnSi_2O_7$
   - b. Trivalent section
     - Melilite (24) $(Ca, Na)_2(Mg, Al)\ (Si, Al)_2O_7$
   - c. Quadrivalent section
     - Na-melilite (26) $Na_2SiSi_2O_7$
     - Gehlenite (26) $Ca_2SiAl_2O_7$

b. Hydrous.

1. Meliphanite family[6] $(Ca, Na)_2Be(Si, Al)_2(O, OH, F)_7$
   - Leucophanite (27) $(Ca, Na)_2BeSi_2(O, OH, F)_7$ Orthorhombic
   - Meliphanite (27) $(Ca, Na)_2Be(Si, Al)_2(O, OH, F)_7$ Tetragonal
2. Complex division

$$\underline{\textit{Zunyite}}\ (28)^{7}\ \mathrm{Al}_{12}\left|\begin{array}{l}(\mathrm{Si_2O_7})_2\\ \mathrm{SiO_2}\\ \mathrm{AlO_4}\end{array}\right|(\mathrm{OH,\ F})18\mathrm{Cl.\ Isometric}$$

II–V

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[4] M. Fleischer gives the above formula for aenigmatite, basing it upon chemical analyses and the dimensions and density of the unit cell. The structure has not been adequately determined.

[5] The members of the melilite family can be referred, for classification, with almost equal propriety to two different types. If the Y(Mg, Fe, Zn, Si, Al) atoms be viewed as kations, the $(Al, Si)_2O_7$ groups being considered the only anions, the formula becomes $X_2Y(Si, Al)_2O_7$, as written above, and the family is a member of the orthodisilicates of type II. If, however, both the paired $(Si, Al)_2O_7$ and the YO_4 tetrahedra (see Figure 3), are considered anions, then, since they are united by their solid angles, they form sheet-like structures and the formula becomes $X_2\left|\begin{array}{l}Si_2O_5\\ YO_2.\end{array}\right.$ In the latter case the melilites may be viewed as complex silicates related structurally to epididymite $Na(BeOH)\left|\begin{array}{l}Si_2O_5\\ SiO_2.\end{array}\right.$

The original investigators of the structures wrote their formula in the first way, as we do. C. Hermann and his associates, in the second volume of the *Structurbericht* (**1936**, pp. 541–543) classify them as forming two-dimensional sheets.

[6] The constitution of the meliphanite family has been studied by W. H. Zachariasen, who derives the formula given above from chemical analyses, the dimensions and densities of the unit cells and the similarity of their x-ray patterns to those of the melilites. The structure suggested, though not determined, is interesting in that it seems to place O, OH and F, interchangeably, upon the solid angles of the SiO_4 tetrahedra, a condition seemingly not recognized, hitherto, in other adequately studied silicates.

[7] Zunyite may also be regarded as combining types I, II, V, if the AlO_4 tetrahedra be regarded as replacing SiO_4.

III. SiO_4 GROUPS COMBINING BY TWO SOLID ANGLES. METASILICATES, R'_2SiO_3. RINGS AND CHAINS.

A. Rings

1. Three-fold rings, $R_6(SiO_3)_3$

a. Anhydrous.

1. Wollastonite family
    a. Monoclinic section[8]
    Wollastonite (29) $Ca_3(SiO_3)_3$
2. Benitoite (30) $BaTi(SiO_3)_3$ Hexagonal

b. Hydrous.

1. Pectolite family (31)[9] Triclinic-Pseudomonoclinic
    Pectolite* $NaHCa_2(SiO_3)_3$
    Schizolite* $NaH(Ca, Mn)_2(SiO_3)_3$
2. Tourmaline family (32)*[10] $XY_9B_3Si_6O_{27}(O, OH, F)_4$ Trigonal
    X=(Ca, Na K, Mn) Y=(Mg, Fe, Al, Cr, Mn, Ti, Li)

2. Six-fold rings, $R'_{12}(SiO_3)_6$.

a. Anhydrous.

1. Beryl (33) $Be_3Al_2(SiO_3)_6$. Hexagonal
2. Cordierite (34) $(Mg, Fe)_2Al_3(Si_5Al)O_{18}\mp H_2O$. Orthorhombic

B. Chains.

1. Chains unilateral, R'_2SiO_3.

1. Pyroxene family $(X, Y)_2(Si, Al)_2O_6$
    X=(Ca, Na, K, Mn) Y=(Mg, Fe, Al, Ti, Li, Mn)
    a. Orthorhombic system (35) Mg, Fe series
        Enstatite $MgSiO_3$
        Bronzite (36) $(Mg, Fe)SiO_3$
        Hypersthene $(Fe, Mg) SiO_3$
    b. Monoclinic system (37)
        1. Bivalent section
            a. Mg, Fe series
                Clinoenstatite $Mg_2Si_2O_6$
            b. Ca, Mg series $Ca(Mg, Fe)Si_2O_6$
                Diopside (38) CaMg
                Hedenbergite CaFe

---

[8] The wollastonite family occurs in both monoclinic and triclinic sections. M. Barnick, who has determined the ring structure of monoclinic wollastonite, suggests that the triclinic form may have a similar structure, but differs in the lesser symmetry of its cells. Vogtite is a Mn bearing variety $(Ca, Mn)SiO_3$ of the triclinic section.

[9] The work of M. A. Peacock has shown so close a relation between the triclinic wollastonite and pectolite families as to suggest similarity of structures. As stated above, M. Barnick has established the ring structure of monoclinic wollastonite and suggests a similar structure for the triclinic form. The true structure of the pectolite family, however, is not definitely known.

[10] F. Machatschki gives the above formula for tourmaline, save that he unites the $(O, OH, F)_4$ group with the O, the latter thus becoming $(O, OH, F)_{31}$. He derives the formula from chemical analyses and the dimensions and density of the unit cells. The formula suggests a possible position of tourmaline in this division, but its structure and place in the classification are unknown. The work of Machatschki is interesting as an effort to unravel somewhat of the complexity of this difficult family.

2. Trivalent section[11] (Ca, Na) (Mg, Fe, Al) $(Si, Al)_2O_6$
   - a. Ca, Mg series
     - Augite[12] $X_mY_{2-m}(Si, Al)_2O_6$
       - X=(Ca, Na, Al, Mn). Y=(Mg, Fe, Al, Ti, Mn).
   - b. Ca, Na, Li series $R'_4Si_2O_6$
     - Acmite NaFe'''
     - Jadeite NaAl
     - Spodumene LiAl

2. Complex division. Bilateral chains, $R'_6\left|\begin{matrix}Si_2O_6\\ Si_2O_5\end{matrix}\right.$

b. Hydrous.

1. Serpentine family
   - *Chrysotile* (39) $(MgOH)_6Si_2O_6, Si_2O_5 \cdot H_2O$ Monoclinic
2. Amphibole family $R''_{7-8}(Si, Al)_4O_{12}, (Si, Al)_4O_{10}(OH, F)_2$
   - a. Orthorhombic system
     - 1. Mg, Fe series
       - *Anthophyllite* (40) $(Mg, Fe)_7Si_4O_{12}, Si_4O_{10}(OH)_2$
   - b. Monoclinic system (41)
     - 1. Bivalent section
       - a. Mg, Fe series $(Mg, Fe)_7Si_4O_{12}, Si_4O_{10}(OH)_2$
         - *Kupfferite* Mg_7
         - *Cummingtonite* (42) $(Mg, Fe)_7$
         - *Grunerite* Fe_7''
       - b. Ca, Mg series $Ca_2(Mg, Fe'')_5Si_4O_{12}, Si_4O_{10}(OH, F)_2$
         - *Tremolite* (43) Ca_2Mg_5
         - *Actinolite* $Ca_2(Mg, Fe'')_5$
     - 2. Trivalent section (42) $X_{2-3}Y_5(Si, Al)_4O_{12}, (Si, Al)_4O_{10}(OH, F)_2$
       - X=(Ca, Na, K, Mn), Y=(Mg, Fe, Al, Mn, Ti)
       - a. Na rich series[13] $R'_{14}Si_8O_{22}(OH)_2$
         - *Glaucophane** $Na_2(Mg, Fe'')_3(Al, Fe''')_2$
         - *Riebeckite** $Na_2Fe''_3Fe'''_2$
         - *Arfedsonite** $Na_2Fe''_4Fe'''_1$
       - b. Na poor series $R'_{15-16}(Si, Al)_8O_{22}(OH, F)_2$
         - *Hornblende*[14] $X_{2-3}Y_5$

---

[11] Formulae have been proposed for various other members of the pyroxene family but the results seem too insecure to render it desirable to present them at this place.

[12] B. E. Warren and J. Biscoe cite the presence of H_2O in some augites and write the formula $X_mY_{2-m}(Si, Al)_2(O, OH, F)_6$.

[13] The species here listed have had formulae assigned to them by Winchell, Bragg and others, based upon their analogies to the studied amphiboles, but their structures are not adequately known. The formulae here given are those of Winchell. (A. N. Winchell, *Elements of Optical Mineralogy*, pt. II, p. 239, **1933**, W. L. Bragg, *Atomic Structure of Minerals*, p. 185, **1937**.) See also B. Gossner, F. Spielberger, *Zeits. Krist.*, **72**, 111 , 1929, B. Gossner, F. Mussgnug, *N. Jb. Min., A. Beil. Bd.*, **58**, 213, 1928.

[14] Osannite (44) is a variety of hornblende with abnormally high O content and high Na.

Additional varieties of hornblende have been examined by B. Gossner and F. Spielberger (*Zeits. Krist.*, **72**, 111, 1929) who derived their formulae from chemical analyses and measurements of the unit cells. The formulae they propose may be written as follows—

Barkevikite $(Ca, Na)_2Mg_2(Fe, Al)_4(SiO_3)_8$
Kärsutite $(Ca, Na)_2(Mg\ Al, Fe)_6.[(Si, Ti)O_3]_8$

IV. SiO_4 GROUPS COMBINED BY THREE SOLID ANGLES. METADISILICATES, $R'_2Si_2O_5$ SHEETS

1. *Bivalent and Trivalent Silicates. Hydrous.*

A. Si_2O_5 series

1. Apophyllite (45) $4CaSi_2O_5 \cdot KF \cdot 8H_2O$. Tetragonal
2. Kaolin family (46) $Al_2Si_2O_5(OH)_4$. Monoclinic
    - Kaolinite (47)[15] $Al_2Si_2O_5(OH)_4 \cdot \beta = 101°30'$
        - var. Anauxite (48)[16] $AlSi_2(O, OH)_5(OH)_{1-2}$
    - Dickite (49) $Al_2Si_2O_5(OH)_4 \cdot \beta = 96°50'$
    - Nacrite (50)[17] $Al_2Si_2O_5(OH)_4 \cdot \beta = 91°43'$
3. Halloysite (51) $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$ Monoclinic

B. Si_4O_{10} series

a. $R'_{6-8}(Si, Al)_4O_{10}(OH)_2$ division

1. Montmorillonite family (52)[18] $(Mg, Al, Fe)_{2-3}(Si, Al, Fe)_4O_{10}(OH)_2 \cdot nH_2O$. Orthorhombic
    - Montmorillonite $(Mg, Al)_{2-3}4H_2O$. Little or no Si replaced by (Al, Fe)
    - Nontronite $(Mg, Al, Fe)_{2-3}nH_2O$. Up to 1 Si replaced by (Al, Fe)
2. Talc—Pyrophyllite group (53) $(Mg, Al)_{2-3}(Si_4O_{10})(OH)_2$. Monoclinic
    - Talc Mg_3
    - Pyrophyllite Al_2
3. Mica families (54) $R'_{7-8}(Si, Al)_4O_{10}(OH)_2$. Monoclinic
    - a. Elastic micas[19]. One Al replacing Si. $R'_7(Al_1Si_3)O_{10}(OH, F)_2$
        - Muscovite (55) $KAl_2(Al_1Si_3)O_{10}(OH, F)_2$
            - var. Phengite. Muscovite+$KAl(Mg, Fe)Si_4O_{10}(OH, F)_2$
        - Paragonite $NaAl_2(Al_1Si_3)O_{10}(OH, F)_2$

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[15] The formula given is based upon the structure determined by L. Pauling (*Proc. Nat. Acad. Sci.*, **16**, 578, 1930) developed further by J. W. Gruner (*Zeits. Krist.*, **83**, 75, 1932). C. J. Ksanda and T. F. W. Barth pointed out certain difficulties based upon a study of dickite (*Am. Mineral.*, **20**, 631, 1935). The structure given by Gruner has been confirmed by S. B. Hendricks (*Zeits. Krist.*, **95**, 247, 1936) with a slight modification in the value of β.

[16] Anauxite forms an isomorphous series with kaolinite. It may be considered derived from kaolinite by the removal of either $Al(OH)_3$ or $AlO(OH)$ from kaolinite. In the latter case an OH group is substituted for one O atom in a Si_2O_5 group. (S. B. Hendricks, *Zeits. Krist.*, **95**, 247, 1936).

[17] Allophane is an amorphous body with approximately the composition of kaolinite. (C. S. Ross, P. F. Kerr, *U. S. G. S.*, *Prof. Paper* **185 G.** 1934.)

[18] J. W. Gruner makes the formula of this family $(Al, Fe)_8 (Al, Fe)_nSi_{16-n}O_{40}(OH)_8 \cdot mH_2O$ and regards montmorillonite, beidellite and nontronite as a continuous isomorphous series with n varying in value from 0 to 4. In montmorillonite $n=0$ or <1, in nontronite $n=2$ to 4. In beidellite and other varieties n lies between these limits.

[19] The species of elastic micas are subject to wide variation in composition. The following replacements occur in them according to J. Holzner (*Zeits. Krist.*, **95**, 435, 1936), $R'_7 = X_1Y_{2-3}$ where X=(K, Na, Ca), Y=(Mg, Fe, Al, Mn, Li). Fe''' may replace Al in $(Al_1Si_3)O_{10}$. Holzner also suggests certain other replacements that seem less assured, i.e. (X, Y'') and (Ti, Si) in some micas and (Na, Li) in lepidolite and zinnwaldite.

Holzner recognizes two structural types of elastic micas, muscovite Y_2 and phlogopite Y_3, and regards biotite as an intergrowth of sheets of both.

Phlogopite $KMg_3(Al_1Si_3)O_{10}(OH, F)_2$
Biotite (56)[20] $K(Mg, Fe, Al)_{2-3}(Al, Si)_4O_{10}(OH, F)_2$
b. Brittle micas. Two Al replacing Si. $R'_8(Al_2Si_2)O_{10}(OH)_2$
Margarite $CaAl_2(Al_2Si_2)O_{10}(OH)_2$
4. Vermiculites (57) $(Mg, Fe)_{2-3}(Si, Al, Fe''')_4O_{10}(OH)_2 \cdot 4H_2O$. Monoclinic

b. $R'_{13-14}(Si, Al)_4O_{10}(OH)_8$ division

1. Chlorite group (58) $R'_{13-14}(Si, Al)_4O_{10}(OH_8)$ Monoclinic
   a. Clinochlore family. One Al replacing Si
      $R'_{13}(Al_1Si_3)O_{10}(OH)_8$. $R'_{13}=(Mg, Fe,'' Mn)_6(Al, Fe''')$
   b. Amesite family. Two Al replacing Si
      $R'_{14}(Al_2Si_2)O_{10}(OH)_8$. $R'_{14}=(Mg, Fe'', Mn'')_4(Al, Fe''')_2$

2. *Complex division*

1. *Epididymite* (59) $Na(BeOH)\left|\begin{array}{l}Si_2O_5\\ SiO_2\end{array}\right.$ Orthorhombic
   IV–V

V. SiO$_4$ GROUPS COMBINED BY FOUR SOLID ANGLES. DIOXIDE TYPE, SiO$_2$. NET-WORKS

A. *R''' free.* SiO$_2$

1. Three-fold. Quartz (60) $(SiO_2)_3$ Trigonal
2. Six-fold. $(SiO_2)_6$
   Cristobalite (61) Cubic packing. Orthorhombic? Isometric
   Tridymite (62) Hexagonal packing. Orthorhombic, Hexagonal

B. *Trivalent Silicates*

1. Anhydrous.

a. Silicates without other anions. Monanionic.

1. Feldspar family (63) $R'_{1-2}(Si, Al)_4O_8$
   a. Monoclinic system
      Orthoclase (64) $KAlSi_3O_8$
      Hyalophane $KAlSi_3O_8 \cdot BaAl_2Si_2O_8$
      Celsian $BaAl_2Si_2O_8$
   b. Triclinic system
      Microcline $KAlSi_3O_8$
      Albite (65) $NaAlSi_3O_8$
      Anorthite $CaAl_2Si_2O_8$
2. Danburite (66)[21] $CaB_2Si_2O_8$. Orthorhombic

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[20] The above formula is that of J. Holzner. A. N. Winchell writes $K(Mg, Fe, Al)_3(Al, Si)_4O_{10}(OH)_2$ (*Am. Mineral.*, **20**, 773, 1935).

[21] Danburite consists of pairs of SiO$_4$ tetrahedra joined by one solid angle, with the formula Si_2O_7 and similarly joined pairs of BO$_4$ tetrahedra with the formula B_2O_7. Both the Si_2O_7 and B_2O_7 pairs are further united by their solid angles to form a net-work. If the Si_2O_7 pairs alone be viewed as anions, danburite is clearly an orthodisilicate, $CaB_2OSi_2O_7$. If boron is viewed as replacing Si, in a manner analogous to the replacement of Si by Al, the structure is of the dioxide type and the formula becomes $CaB_2Si_2O_8$ as here written. The small size and trivalent valency of the B atom has led us to treat the subject in the latter way.

3. Leucite family (67)*[22] $R'AlSi_2O_6$ Tetragonal—Pseudo-isometric
    - Leucite $KAlSi_2O_6$
    - Na-Leucite $(K, Na)AlSi_2O_6$
4. Nepheline family (68) $R'AlSiO_4$. Hexagonal
    - Nepheline (α carnegeite) $NaAlSiO_4$
    - Kaliophilite $KAlSiO_4$

b. Silicates with other anions. Polyanionic.

1. Scapolite family (69) $3\,(Na, Ca)\,(Al, Si)_4O_8+[NaCl, Ca(CO_3, SO_4)]$ Tetragonal
    - Marialite. 3 albite+NaCl
    - $\left.\begin{array}{l}\text{Wernerite}\\ \text{Mizzonite}\end{array}\right|$ Marialite+Meionite
    - Meionite. 3 Anorthite+$Ca(CO_3, SO_4)$
2. Sodalite family (70) $(Na, Ca)_{6-3}(AlSiO_4)_6+2X$. Isometric
    - Sodalite $Na_6(AlSiO_4)_6Na_2Cl_2$
    - Noselite (71) $Na_6(AlSiO_4)_6Na_2SO_4$
    - Haüynite (71) $(Ca, Na)_{3-6}(AlSiO_4)_6\,(CaSO_4)_{1-2}$
3. Cancrinite family (72) $3NaAlSiO_4+Ca(Cl_2, CO_3, SO_4)\cdot\pm H_2O$. Hexagonal
    - Cancrinite $3NaAlSiO_4+CaCO_3\pm H_2O$
    - Davynite $3NaAlSiO_4+Ca(Cl_2, SO_4)$
4. Helvite—Danalite group (73). Isometric
    - Helvite $3(Mn, Fe)(Be, Si)O_4+(Mn, Fe, Zn)S$
    - Danalite $3(Zn, Fe, Mn)(Be, Si)O_4+(Zn, Fe)S$

2. Hydrous.

1. Epidote family (74)*[23] $Ca_2(Al, Fe, R''')_3Si_3O_{12}(OH)$
2. Zeolites (75)[24] $R'_m(Al_mSi_n)O_{2(2+n)}\cdot xH_2O$

[22] No adequate study has been made of the structure of leucite but its composition and relations are such as to suggest its position in this group. Recent studies of J. Wyart show its true tetragonal character.

[23] The structure of the epidote family is not adequately known. D. J. Bujor studied epidote and clinozoisite and published his roentgenographic data in 1931, in the first of two articles. The second part, embracing his interpretation of the data, has not yet appeared. A. N. Winchell has referred the family to the division of three-dimensional lattices. This has a certain plausibility because of the relation of epidote to feldspar. Waldbauer and McCann have shown that orthorhombic zoisite is probably formed by the submicroscopic twinning of clinozoisite.

[24] Different views have been held concerning the composition of the zeolites due to their complexity, variable hydration, isomorphous intergrowths and replacements seemingly taking place after their crystallization. One view, widely held, assigns to most of them two Al atoms (or some multiple of two), a fixed Al:Si ratio, the isomorphous replacement of Ca by Na_2 in many, and a resulting variable number of kations. A second view, suggested by A. N. Winchell, is that CaAl and NaSi mutually replace each other resulting in isomorphous intergrowths, a variable Al:Si ratio and a constant number of kations in each species. Winchell denies the primary replacement of Ca by Na_2 though he believes it may occur subsequent to crystallization. M. H. Hey and J. Wyart believe, on the contrary, that both types of replacement occur.

a. Al_2 section. $R'_2Al_2Si_nO_{2(2+n)} \cdot xH_2O$

1. Si_2O_8 series
   Thomsonite (76)[25] $Na_2Ca_4(Al_2Si_2O_8)_5$. $12H_2O$. Orthorhombic
2. Si_3O_{10} series
   Natrolite (77) $Na_2Al_2Si_3O_{10}$. $2H_2O$. Orthorhombic
   Scolecite (78) $CaAl_2Si_3O_{10}$. $3H_2O$. Monoclinic
   Mesolite (79)*[26] $Na_2Ca_2(Al_2Si_3O_{10})_3$. $8H_2O$. Monoclinic
   Gonnardite (80)*[27] $Na_2Ca(Al_2Si_3O_{10})_2$. $7H_2O$. Orthorhombic or Tetragonal
   Edingtonite (81) $BaAl_2Si_3O_{10}$. $4H_2O$. Tetragonal
3. Si_4O_{12} series
   Analcite (82) $Na_2Al_2Si_4O_{12}$. $2H_2O$ Tetragonal? Pseudo-isometric
   Chabazite (83)[28] $CaAl_2Si_4O_{12}$. $6H_2O$. Rhombohedral
   Pollucite (84)* $CsAl_2Si_4O_{12} \cdot 1H_2O$. Isometric
4. Si_7O_{18} series
   Heulandite (85)*[29] $CaAl_2Si_7O_{18}$. $6H_2O$ Monoclinic
5. Si_8O_{20} series
   Mordenite (86)*[30] $Na_2Ca(Al_2Si_8O_{20})_2$. $12\frac{1}{2}H_2O$. Monoclinic

b. Al_m section

Ashcroftine (87)*[31] $NaK(Ca, Mn, Mg)Al_4Si_6O_{18}$. $8H_2O$. Tetragonal

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[25] Subject to replacements of $CaAl \rightleftarrows NaSi$ and $Ca \rightleftarrows Na_2$, according to M. H. Hey.

[26] Composition doubtful, perhaps $Na_4Ca_6(Al_2Si_3O_{10})_3$. $21H_2O$, (W. H. Taylor et al., *Zeits. Krist.*, **84**, 384, 1933, footnote.)

[27] M. H. Hey gives the above formula and states that CaAl and NaSi replace each other, more rarely Ca and Na_2.

[28] The structure of chabazite was determined by J. Wyart who gives the above formula, subject to various replacements of $Ca \rightleftarrows Na_2$, $CaAl \rightleftarrows NaSi$, etc. A. N. Winchell's formula is $(Na, K, Ca)_7(Al, Si)_{40}O_{80}$. $40H_2O$.

[29] The composition of heulandite varies widely. J. Wyart studied its structure but did not determine the parameters. He gives the above formula subject to various replacements of Ca, Al, Si, especially $Si \rightleftarrows NaAl$. M. H. Hey gives the formula $Na_xCa_yAl_{(x+2y)}Si_{36-(x+2y)}O_{72}$. $24H_2O$.

[30] The above formula is by A. N. Winchell, who bases it upon chemical analyses.

[31] A. N. Winchell adds the following formula of additional species of zeolites, basing them upon selected chemical analyses (*Am. Mineral.*, **10**, 170, 1925. See also ib. **22**, 85, 1937). His kation number ("alkali number") is recalculated for 80 oxygen atoms.

1. Al:Si ratio and composition constant

Levynite $NaCa_4Al_9Si_{16}O_{50}$. $25H_2O$	Kation number 8
Stilbite $Na_3Ca_9Al_{21}Si_{59}O_{160}$. $60H_2O$	Kation number 6
Epistilbite $NaCa_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Brewsterite $Na(Ca, Sr, Ba)_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Harmatome $KBa_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Ptilotite $Na_3Ca_2Al_7Si_{33}O_{80}$. 25? H_2O	Kation number 5?

2. Al:Si ratio and composition variable. Isomorphous intergrowths

Gmelinite $(Na, Ca)_{12}(Al, Si)_{40}O_{80}$. $40H_2O$	Kation number 12 ($11\frac{1}{3}$?)
Gismondite $(K, Ca)_{11}(Al, Si)_{40}O_{80}$. $36–40H_2O$	Kation number 11
Phillipsite $(K, Ca)_{11}(Al, Si)_{40}O_{80}$. $30–40H_2O$	Kation number 11
Laumontite $(Na, Ca)_7(Al, Si)_{40}O_{80}$. $25H_2O$	Kation number 7

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[32] The usual abbreviations are used, save in the following publications—

P. P. Ewald, C. Hermann, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, I, **1931.** Abbreviation, *SB* I **1931.**

C. Hermann, O. Lohrmann, H. Philipp, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, II, **1936.** Abbreviation, *SB* II **1936.**

G. Gottfried, F. Schlossberger, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, III, **1936.** Abbreviation, *SB* III **1936.**

27. Leucophanite and Meliphanite, W. H. Zachariasen, *Zeits. Krist.*, **74,** 226, 1930; *Norske Geol. Tidsskr.*, **12,** 577, 1931.
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CORDIERITE

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Repeated attempts at the University of Wisconsin to obtain a reasonable correlation of composition and optic properties in cordierite on the basis of published data have been unsuccessful, but H. Shibata[1] of the University of Tokyo has solved the problem with the aid of new data on iron-rich cordierite from Japanese pegmatites.

As a basis for some theoretical discussion it may be worth while to present the results of an independent study of the data, although they confirm Shibata's results in general; but Shibata based his correlation on the molecular ratio of $FeO+2Fe_2O_3+Na_2O$ to $MgO+FeO+2Fe_2O_3+Na_2O$; and the writer prefers to use the molecular ratio between $FeO+2Fe_2O_3+MnO$ and $MgO+FeO+2Fe_2O_3+MnO$. Manganese is not common and never abundant in cordierite, but it resembles iron so closely, both in its chemical nature and its effects on optical properties, that it should be included with it. Analyses of cordierite do not show that ferric iron replaces alumina, because some analyses have been made on impure material or by inaccurate methods, and the tenor of ferric iron is always low. On the other hand the ferric iron may represent iron which was ferrous at the time of formation of the mineral; but in any case its influence on the optic properties is similar to that of an equivalent tenor of ferrous iron. Shibata includes soda with iron in his calculations, although he suggests that it plays an entirely different role in the crystal, namely, the same role as that of alkalies in beryl. It is true that one sample[2] of cordierite is reported to have properties such that it fits the diagram better when soda is included with iron, but the writer regards this as the result of chance, especially in view of the fact that soda has effects on physical properties in all other minerals very different from those of iron.

The relations between composition (excluding sodium and including manganese with iron) and physical properties are shown in Fig. 1. Artificial $Mg_2Al_4Si_5O_{18}$ is negative[3] and uniaxial, or nearly so, with $N_g=N_m=1.528$ and $N_p=1.524$. This has been considered to be artificial pure magnesian cordierite, but the diagram (Fig. 1) suggests that it is a different phase, since the magnesian end member of natural cordierite would almost certainly be positive (although Shibata sketches a sharp reversal of the $2V$ curve to a uniaxial negative end member). Of course it is also possible that natural magnesian cordierite differs from the artificial compound chemically—for example, by the presence of water—enough to change the optic sign. In any case, Tsuboi[4] supplies evidence that natural cordierite in a single rock varies in optic angle from positive, near 0°, to negative and nearly uniaxial, though most of the grains are of very large optic angle, near 90°, of both optic signs! From the diagram (Fig. 1) the pure magnesian cordierite might be uniaxial positive, and cordierite with about 40 per cent iron might be of small optic angle. But it seems

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[1] Shibata, H., Graphic intergrowth of cordierite and quartz in pegmatites from Sasago and Dosi, Province of Kai, Japan: *Jap. Jour. Geol. Geog.*, vol. **13**, p. 205, 1936.

[2] Cordierite from Haddam, Conn., analyzed by M. Dittrich and studied by L. Oppenheimer: *N. J. Min.*, I, p. 175, **1915.**

[3] Rankin, G. A., and Merwin H. E., *Am. Jour. Sci.*, vol. **215**, p. 301, 1918. Also Greig, J. W., *Am. Jour. Sci.*, vol. **13**, p. 41, 1927.

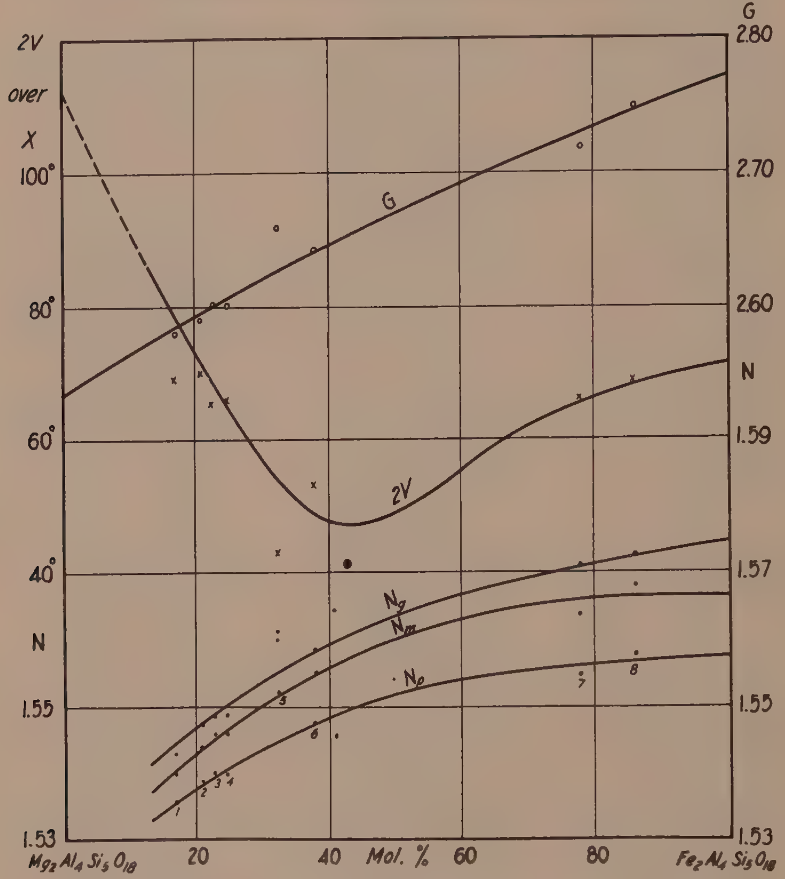

FIG. 1. Variations in composition and physical properties in cordierite.

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[4] Tsuboi, S. *Jap. Jour. Geol. Geog.*, vol. **13**, p. 337, 1936.

probable that some other factor (besides Fe+Mn) has a considerable influence on the optic angle.

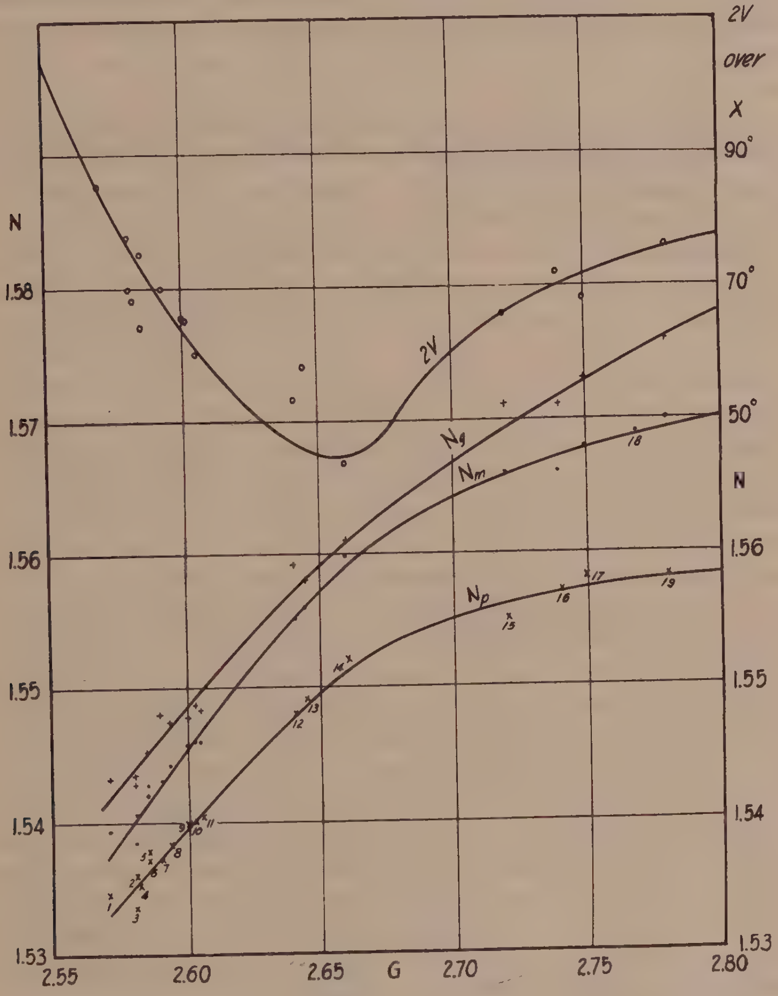

FIG. 2. Relations between specific gravity and optic properties in cordierite.

Shibata called attention to the fact that the specific gravity curve is nearly a straight line; assuming it to be actually straight, he used it as the basis of a second diagram of the optic properties. The writer has repeated this work and obtained a result quite similar to Shibata's diagram; it is shown in Fig. 2. This diagram is significant for at least two reasons. First, as compared with Fig. 1, more than twice as many samples of cordierite are available for use in it, and this results in fixing more completely and more accurately the course of the curves for the optic properties. Second, there is clearly a closer correlation of optic properties with measured specific gravities than with chemical analyses. This is another reason why the curves of optic properties can be drawn more accurately.

An explanation of these conditions is not difficult. Professor R. C. Emmons in the Mineral Laboratories of the University of Wisconsin has found repeatedly that the indices of refraction of cordierite vary considerably, not only in different crystals from a single rock, but even in various parts of a single crystal. The observations reported by Tsuboi[5] are further evidence of the variability in the optic properties. There is no reason to doubt that these variations in optic properties are largely or wholly the result of variations in composition. Accordingly, a chemical analysis of cordierite separated from some rock, which must ordinarily be made on an aggregate of scores or even hundreds of small crystals or crystal fragments, represents the average composition of the aggregate, whereas the measurements of the optic properties, made on some part of one crystal, may differ notably from average values. On the other hand, the specific gravity may be determined from the same crystal used for the optical measures. It is therefore to be expected that there will be a closer correlation between specific gravity and optic properties than between chemical composition and optic properties.

Of course it is true that the closer correlation may be due to other causes. For example, the specific gravity depends upon all the chemical variations, and not only on those used in the diagram. But this does not seem to be important, since the other variations in composition are of types that have minor effects on the optic properties in other minerals.

The lack of correlation between chemical composition and optic properties is illustrated by the fact that there are almost as many (seven) samples of cordierite which have been analyzed and measured optically that can not be used in the diagram as the number (eight) used in preparing it. Of course this condition explains the fact that previous attempts to find a correlation have not succeeded.

An examination of Fig. 2 reveals some points of special interest. Thus, the curve for N_m approaches closest to that for N_g at about $G.=2.654$, just as it should to correspond with an optic angle of about 40° about X; likewise it is about halfway between N_g and N_p at $G.=2.568$, which corresponds with $2V=90°$. This diagram makes it very improbable that the optic angle can be 0° about X (with $N_m=N_g$) at $G.=2.55$, which is near the value for pure $Mg_2Al_4Si_5O_{18}$. But the optic angle seems to be widely variable for a single value of the refractive index, if the results of Tsuboi are accurate: he reported finding a nearly uniaxial positive cordierite having $N_m = 1.560$! Can this be due to a variation in the tenor of water?

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[5] Tsuboi: *Op. cit.*

REFERENCES FOR FIG. 1

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2. Tsilaisina, Duparc, L., Wunder, M. and Sabot, R.: *Bull. Soc. Fr. Min.*, vol. **33,** p. 53, 1910.
3. Guilford, Conn., Farrington, O. C.: *Am. Jour. Sci.*, vol. **43,** p. 14, 1892, for analysis, and Oppenheimer, L.: *N. J. Min.*, I, p. 175, **1915,** for properties.
4. Bodenmais, Oppenheimer, L.: *Op. cit.*
5. Haddam, Conn., Oppenheimer, L.: *Op. cit.*
6. Watarase, Shibata, H.: *Jap. Jour. Geol. Geog.*, vol. **13,** p. 205, 1936.
7. Mujinazawa, Shibata, H.: *Op. cit.*
8. Sasago, Shibata, H.: *Op. cit.*

REFERENCES FOR FIG. 2

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2. Twedestrand, Oppenheimer, L.: *Op. cit.*
3. Orijarvi, Oppenheimer, L.: *Op. cit.*
4. Hitachi, Shibata, H.: *Op. cit.* for G. and Kozu, S. and Watanabe, M.: *Jour. Jap. Assoc. Min. Pet.*, III, p. 327, **1930,** for optic data.
5. Ceylon, Oppenheimer, L.: *Op. cit.*
6. Dosi, Shibata, H.: *Op. cit.*
7. Träskböle, Eskola, P.: *Bull. Com. Geol. Finlande*, vol. **40,** p. 172, 1914.
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10. Bodenmais, Oppenheimer, L.: *Op. cit.*
11. Guilford, Conn., Oppenheimer, L.: *Op. cit.*
12. Watarase, Shibata, H.: *Op. cit.*
13. Tsukuba, Shibata, H. for G. and Yoshiki, B.: *Jour. Jap. Assoc. Min. Pet.*, vol. **10,** p. 159, 1933, for optic data.
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15. Mujinazawa, Shibata, H.: *Op. cit.*
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19. Naegi, Shibata, H.: *Op. cit.*

A STUDY OF MISSOURI GLAUCONITE*

VICTOR T. ALLEN, *St. Louis University, St. Louis, Mo.*

INTRODUCTION

The conclusions of E. W. Galliher[1] that glauconite is forming from biotite in Monterey Bay, and of John W. Gruner[2] that the molecular structure of Bonneterre glauconite is similar to that of biotite from Mora, Minnesota, led me to test the possibility that Missouri glauconite has formed from biotite. Several years ago I observed[3] that anauxite from the Ione formation of California which had formed from biotite contained rutile needles similar to those in biotite, and studies of clay[4] carried on by the Missouri Geological Survey afford evidence that titanium is concentrated along with aluminum during the change of flint clay to diaspore clay. The titanium content of glauconite, especially that present as rutile, seemed a logical starting point in this study. A survey of the published analyses of glauconite showed that little attention had been given to the titanium of glauconite, for only three or four record even a trace.

GLAUCONITE OF THE BONNETERRE DOLOMITE

Certain layers of the Bonneterre dolomite of Cambrian age contain forty to fifty per cent glauconite. The glauconite of this formation was studied by C. S. Ross[5] and all the constituents except titanium, listed as No. 4 in the accompanying table, were determined by G. V. Brown. Glauconite was separated from an outcrop of the Bonneterre dolomite along U. S. Highway 61 about twelve miles south of Farmington, Missouri, and the titanium determined by R. T. Rolufs, chemist of the Missouri Geological Survey. It contained 0.1 per cent titanium oxide and thin sections showed the absence of rutile needles in the glauconite. Galliher was kind enough to send me what remained of the samples used in his published analyses[6] which are given as 1, 2, 3, in the accompanying table.

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* Published with the permission of the Director of the Missouri Geological Survey.

[1] Galliher, E. W., Glauconite genesis: *Bull. Geol. Soc. Am.*, vol. **46,** pp. 1351–66, 1935.

[2] Gruner, John W., The structural relationship of glauconite and mica: *Am. Mineral.*, vol. **20,** pp. 699–714, 1935.

[3] Allen, Victor T., Anauxite from the Ione formation of California, *Am. Mineral.*, vol. **13,** p. 150, 1928.

[4] McQueen, H. S., Geologic relations of the diaspore and flint fire clays of Missouri: *Jour. Am. Cer. Soc.*, vol. **12,** pp. 687–697, 1929.

Allen, Victor T., Mineral composition and origin of Missouri flint and diaspore clays: *Missouri Geological Survey and Water Resources*, 58th Bienn. Report, App. **IV,** pp. 1–24, 1935.

[5] Ross, C. S., The optical properties and chemical composition of glauconite: *Proc. U. S. Nat. Mus.*, vol. **69,** pp. 1–15, 1926.

[6] *Loc. cit.*, p. 1359.

The titanium in these samples was determined by Mr. Rolufs. The spongy glauconite contains three times the titanium, and the firm glauconite six times the titanium present in the glauconite of the Bonneterre formation, and both contain occasional rutile needles which are more common in the biotite from Monterey Bay. Galliher's evidence[7] of the derivation of Monterey glauconite from biotite is convincing, and the reactions involved seem simpler than those in the formation of glauconite by colloidal silica and ferric hydroxide derived from the decomposition of clay reacting with potassium in sea water.[8] According to Galliher[9] the change of biotite to glauconite involves: oxidation of its iron, retention of its potash, hydration, partial loss of alumina and magnesia. To this must now be added a partial loss of titanium from more than 3 per cent in biotite to .3 or less per cent in glauconite. The oxidation of iron in a black mud environment under anaerobic conditions, where slow sedi-

	(1) Biotite Monterey Bay, Calif.	(2) Firm Glauconite Monterey Bay, Calif.	(3) Spongy Glauconite Monterey Bay, Calif.	(4) Glauconite Bonneterre Dolomite, Missouri	(5) Biotite Mora, Minn.
SiO_2	36.25	55.95	51.90	48.66	35.67
Al_2O_3	18.25	11.56	1.52	8.46	14.56
Fe_2O_3	6.35	9.99	27.98	18.80	3.03
FeO	17.09	2.02	1.26	3.98	23.23
MgO	9.01	6.77	4.67	3.56	9.24
CaO	0.79	3.95	0.89	0.62	1.13
Na_2O		0.61	0.53	none	0.49
K_2O	8.68	4.12	4.90	8.31	8.06
H_2O-		1.60	2.10	1.94	0.23
H_2O+	2.70	3.22	4.05	4.62	1.02
Others		0.18	0.11	0.12	0.24
TiO_2*	3.26*	0.59*	0.30*	0.10*	3.32
Refractive Index γ	1.645	1.618	1.618	1.618	1.655

No. 1, 2, 3. Analyses by A. A. Hanks, see E. W. Galliher, *Bull. Geol. Soc. Am.*, vol. **46**, p. 1359, 1935.

No. 4. Analysis by G. V. Brown, see C. S. Ross, *Proc. U. S. Nat. Museum*, vol. **69**, pp. 1–15, 1926.

No. 5. Analysis by F. F. Grout, *Am. Mineral.*, vol. **9**, p. 161, 1924.

* No. 1, 2, 3, 4, TiO_2 determinations by R. T. Rolufs, Chemist, Missouri Geological Survey.

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[7] *Loc. cit.*

[8] Murray, John, and Renard, A. F.: *Report of the Challenger Expedition, Deep Sea Deposits*, p. 385, **1891.**

[9] *Loc. cit.*, pp. 1357–1360.

mentation allows time for the reactions to take place, is explained by Galliher as due to dehydrogenation following hydrolysis. But, in spite of the attractiveness of the method from the chemical side, its application to the glauconite of the Bonneterre formation meets with other difficulties besides a scarcity of titanium. Not the least of these are suitable source rocks to furnish this large quantity of biotite, for the pre-Cambrian granites of Missouri are poor in biotite. If we postulate a buried area of biotite schists as the source material, we would expect that an occasional metamorphic mineral attached to a large biotite flake would be rafted to the site of deposition. Attempts to concentrate the heavy minerals from large samples of the Bonneterre dolomite indicate the absence of metamorphic minerals and a great scarcity of any heavy minerals. Furthermore, the arrangement of the glauconite along the bedding of the dolomite is not that common in micaceous sediments, for clusters of glauconite often end abruptly instead of grading out along the same horizontal layer, due to the ease with which the plates float during deposition.

Glauconite in the St. Peter Sandstone

The same objections apply to the glauconite-like mineral that coats the surface of sand grains in the upper part of the St. Peter sandstone of Missouri. I use the term "glauconite-like mineral" because its greatest refractive index, gamma, is about 1.58 instead of the usual 1.62 or 1.63 of glauconite. But the green mineral of the St. Peter sandstone has the peculiar spotted interference colors that characterize all the glauconite examined. Galliher would term this green film on the quartz grains pigmentary glauconite, which he considers forms by tiny particles breaking off the spongy type. The lack of visible rutile needles and a satisfactory source for the glauconite, or the biotite, stands in the way of accepting this explanation.

Glauconite in Clayton and Porters Creek Formations

In southeastern Missouri at Crowleys Ridge near the town of Ardeola are two Eocene formations that contain glauconite, the Clayton and the overlying Porters Creek. The glauconite of these formations contains occasional rutile needles and the sediments contain a small metamorphic assemblage including such minerals as kyanite, epidote, and garnet that probably came from the Appalachian region to the east. In a published paper[10] I have presented evidence that the Porters Creek formation of Missouri is bentonitic and that the montmorillonite in it formed from the decomposition of volcanic ash, for relict volcanic textures are common in the lower twenty feet of the formation. Parts of the Porters Creek formation contain 2 or 3 per cent of muscovite which exceeds the glauconite present. If 2 or 3 per cent of muscovite could float in from a distant terrane, it is reasonable to believe that half that amount of biotite could accompany it and later be changed to glauconite according to the reactions described by Galliher.

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[10] Allen, Victor T., Petrography and origin of the Fuller's earth of southeastern Missouri: *Econ. Geol.*, vol. **29**, pp. 590–598, 1934.

CONCLUSIONS

From this study it appears that the glauconite in the two Eocene formations of Missouri, the Porters Creek and the Clayton, could well have formed from biotite, but similar substantiating evidence is lacking for a like origin of the glauconite in the two older formations of Missouri, the St. Peter sandstone of Ordovician age and the Bonneterre dolomite of Cambrian age.

NOTES AND NEWS

A NEW LOCALITY FOR AUTUNITE

E. S. C. Smith, *Union College* and
E. O. E. Maslowski, *Schenectady, N. Y.*

Autunite has been reported previously from pegmatites at the following places in the State of Maine: Mt. Apatite, Auburn, Androscoggin County; the Nevel Mine, Hall's Ridge, Newry, Mt. Mica, Paris, Black Mountain, Rumford and Harndon Hill, Stoneham, all in Oxford County; and at Topsham in Sagadahoc County. This brief note is to point out a new locality for autunite at the Hooper's Ledge feldspar quarry, now long since abandoned, which is one and a half miles north-east of South Paris village and a mile south of Mt. Mica. On one of the dumps three fragments of very dark smoky quartz, about six by four by two centimeters, were found covered with the typical lemon yellow scales and crusts. Some alteration appears to have taken place. Held before the chamber of a Giger counter the response is lively, indicating the presence of abundant radio-active material. Under the mercury arc it fluoresces in the usual manner. This new occurrence of autunite with dark smoky quartz recalls similar association of these minerals at Gilsum, New Hampshire and elsewhere, and suggests interesting possibilities for further investigation.

NEW OCCURRENCE OF MILLERITE

M. A. Northup, *Jersey City, New Jersey.*

Millerite has been found recently at the Sullivan Trail Coal Co. anthracite mine at West Pittston, Pennsylvania. The mineral occurs as radiating tufted groups of very slender fibers in small spaces between crystals of ankerite or quartz. Although fairly abundant, the individual groups are small, varying from 1/16 to ½ inch in length, depending on the free space available. The amount of nickel sulfide carried into such spaces seems to have varied greatly as the fibers in a single group range in number from five or six widely separated ones to closely packed bunches of numerous individuals. Rarely a tuft of short fibers is seen branching out of the tip of a longer single one. The color is pale brass yellow, darkening slightly on exposure, and occasionally in unexposed specimens, developing a greenish gray tarnish.

The quartz and ankerite crystals upon which the millerite occurs are found partially filling vugs in the black shales of the coal measures. Specimens found on the dumps seldom show mineralized surfaces more than 6 or 8 inches square. Generally the vug is almost normal to the schistosity of the rock and is coated on both faces with a layer of ankerite rhombs, often slightly curved. The wider vugs have more or less crystallized quartz in the openings. Where the quartz extends across the hollow, it often shows a series of roughly parallel fractures in one direction which appear to have been produced by pressure due to rock movements subsequent to its deposition, and do not seem related to any crystallographic direction.

Millerite occurs in spaces between the ankerite or quartz crystals, or is found on quartz adjacent to ankerite. As no instances of millerite penetrating either of the two minerals have been observed, the order of deposition is:—ankerite, quartz and millerite. Occasionally a few small crystals of sphalerite also occur on the ankerite.

So far as the author knows, no occurrence of millerite in the Wyoming Valley coal field has been recorded. Gordon[1] mentions a questionable occurrence of the mineral with quartz in siderite, presumably at a coal mine in Scranton, Pa., some nine miles east of the new locality. Since his book represents a survey of the literature on Pennsylvania minerals prior to 1922, it seems reasonable to suppose that its occurrence at West Pittston would have been included by him, had the mineral been discovered. Moreover, until four or five years ago the mine in question had not been worked for a long time. As the author visited it repeatedly in 1936 without finding any millerite, there seems little doubt but that the occurrence here noted is a new one.

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[1] Gordon, S. G., *The Mineralogy of Pennsylvania*, Special Publication No. 1 of The Philadelphia Academy of Natural Sciences.

BOOK REVIEW

DAS MAGMA UND SEINE PRODUKTE, I TEIL:PHYSIKALISCH-CHEMISCHE GRUNDLAGEN. Paul Niggli, Akademische Verlagsgesellschaft m.b.H., *Leipzig*, **1937.** 379 pp., 276 figures. Price, RM 32.

This book is the first volume of what is essentially a second edition of Niggli's earlier book, "Die leichtflüchtigen Bestandteile im Magma " The other volume will bear the subtitle, "Magmatische Gesteine und Minerallagerstätten."

The first volume is concerned entirely with physico-chemical principles and a review of the experimental work that has been done. It is of wider scope than the corresponding part of the first edition, which dealt entirely with systems containing both non-volatile and volatile components. The new edition has a considerable section (110 pages) dealing with the construction and interpretation of diagrams of anhydrous systems, using the published diagrams of such systems as examples. At the end of the text the data for the fundamental ternary systems are given in tabular form.

The outline of the section dealing with systems with components of different volatility has been taken bodily from the first edition, but the text has been revised slightly and brought up to date. Most of the examples are the same, but the figures have been re-drawn and numerous auxiliary explanatory diagrams have been added. Recent experimental and theoretical work on such systems is cited, notably that by Wuite on the system Na_2SO_4–H_2O, that by Eitel and by Niggli on systems with CO_2, and that by Smits (theoretical) on the system H_2O–SiO_2.

This book is a worthy successor to its well-known predecessor, "Die leichtflüchtigen Bestandteile im Magma." The additional data on systems with volatile components would probably not have justified a new edition, but the inclusion of the fundamental anhydrous systems makes it useful not only as an explanation of the theory of phase equilibrium diagrams, but also as a reference book of the important systems that have been worked out experimentally. It is fully illustrated with actual diagrams which are accompanied by lengthy explanatory legends.

The work should be especially useful and convenient when the second volume appears because it will then be possible while studying a given natural process to have the pertinent diagram and data before one at the same time without having to turn to another part of the same volume for them.

Earl Ingerson

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, September 3, 1937

A stated meeting was held with Mr. Baldwin in the chair, and an attendance of 32 members and 17 visitors. Mr. Welton Meisenhelder and Mr. Ralph Carmer, Jr. were elected senior and junior members respectively.

Reports of summer trips constituted the program. Mr. Benge found dolomite, calcite, and minute pyrite in the Valley Forge Cement Co. quarry near West Conshohocken. Mr. Edwin Roedder exhibited large pyromorphite specimens from Phoenixville; clinochlore from Brinton's quarry near West Chester; malachite crystals from Bridgeport, Pa.; molybdenite crystals from Hillburn, N. Y ; and pyrrhotite crystals with black sulfur from Judds Bridge, N. Y.

Mr. Albert Jehle exhibited a four pound mass of bismuthinite from Bedford, N. Y., and some rose quartz. Mr. Leonard Morgan described a trip to Canada, exhibiting chondrodite (Tilly Foster, N. Y.); stilbite and heulandite (Prospect Park, N. J.); quartz crystals (Herkimer); siderite (Antwerp, N. Y.); apatite, tourmaline, moonstone (Cantley, Quebec); molybdenite (Molybdenite mine); titanite crystals, apatite crystals, and hornblende (Lake Clear); ellsworthite (Hybla); uraninite (Wilberforce); fluorite and barite (Madoc).

Dr. W. Hershey Thomas visited Lynchburg and Amelia Court House (albite, amazonstone, tantalite). Mr. Moyd found native copper at Cornwall, Pa.; Mr. Trudell described a trip, with Messrs. Gordon and Moyd to New England visiting Westmoreland, N. H. (fluorite); Acworth (beryl); Grafton, N. H. (uraninite, autunite, uranophane, gummite, albite, apatite). Mr. Cienkowski reported on a lengthy trip through the West.

Wiley Flack, *Secretary*

NEW YORK MINERALOGICAL CLUB

American Museum of Natural History, New York City, Oct. 20, 1937

The meeting was called to order at 8:15 p.m. by Vice-president Andersen, with about 75 members and guests present. The May field trip to Roxbury was reported as successful and final plans presented for the November trip to Strickland's Quarry, Portland, Conn. Siderite, galena, sphalerite, quartz, pyrite and hyalite were found on the May trip in good specimens; hyalite has not been previously reported from the locality and occurs as a crust on siderite.

The members were then invited to give a report upon their collecting activities of the past year. Mr. James G. Manchester described the Tampa Bay chalcedony geode locality, which he visited last winter with E. A. Maynard. The actual locality is around Hillsborough Bay and the best collecting spots were in the Yacht Club basin on Ballast Point and along the 22nd Street Causeway. The corals are now completely silicified and can be safely treated with HCl to remove extraneous material, such as oyster shells and seaweed, before they are broken open to reveal the chalcedony and quartz crystal linings. They are washed and dredged up from Miocene limestone beds and represent varieties of coral no longer to be found in the region. The quantity is unlimited and perpetually self-renewing.

James A. Taylor then gave the results of his collecting trip to the Gaspé Peninsula, where he visited mines and zeolite localities. The Federal Zinc and Lead Mine, now probably permanently closed down, proved to be very inaccessible and the sphalerite did not prove to be of the fluorescent type. Siderite, quartz and a few other minerals were found on the dumps. St. Bonaventure Island appears to be worked out at the agate locality. Partridge Island was found to be the best and most productive zeolite locality at the present time, with some good chabazite coming from Wasson's Bluff. Partridge Island must be visited at low tide, so collecting time is limited, but several visits might produce excellent chabazite as well as stilbite. Many fine specimens can be obtained from the cliffs, but the material on the beach is abundant and many reasonably fresh blocks can be collected. Cape Blomiden appears to be exhausted. A gypsum quarry at Windsor was a locality for anhydrite and all kinds of gypsum.

C. W. Hoadley, H. Gray, M. McKown, J. Boyle, J. Morton, H. C. Grahl, G. S. Stanton and Scott Ellis also showed specimens collected on less extended trips during the summer

F. H. Pough, *Secretary*

MINERALOGICAL SOCIETY OF AMERICA

EIGHTEENTH ANNUAL MEETING

NORMAN L. BOWEN, *President*
PAUL F. KERR, *Secretary*

Washington, D. C.
December 28–30, 1937

The annual meeting of the Mineralogical Society of America will be held in the Hotel Washington in conjunction with the Geological Society of America. It is planned to hold three sessions. The first session will be on Tuesday, December 28th at 2:00 P.M., and the second session on Thursday, December 30th, at 9:30 A.M. A joint session with the Geological Society of America for the presentation of papers on petrography will be held Wednesday, December 29th, at 2:00 P.M.

The presidential address of Dr. Norman L. Bowen, entitled *Mente et Malleo Atque Catino*, will be presented before the general session of all societies on Wednesday morning, December 29th.

The annual luncheon of the Mineralogical Society, for members and their friends, at which the first award of the Roebling Medal for Meritorious Achievement in Mineralogy is to be made, will be held on Wednesday, December 29th, at 12:15 P.M. in the Hotel Washington.

With the reduced railroad rates in effect, no certificates are offered for the use of Society members, but many railroads offer round trip rates for a limited period.

PRELIMINARY LIST OF PAPERS

BEREK, M. (presented by H. W. Zieler)—**Optical Methods of Measuring in Reflected Polarized Light.**
BUERGER, M. J.—**Surface Reflection Areas in Weissenburg Photographs.**

CAMERON, EUGENE N.—**Mineral Deposits of the Northeastern Humboldt Range, Nevada.**

DONNAY, J. D. H.—**The Significance of Crystal Habit.**

FISHER, D. JEROME—**U-stage Axial Angle Apparatus.**
FISHER, D. JEROME—**Stereoscopic Crystal Drawing.**

GORDON, SAMUEL G.—**Making Structure Models.**
GORDON, SAMUEL G.—**The New Mineral Hall of the Academy of Natural Sciences of Philadelphia.**

HAWKINS, A. C.—**Twinning in Glauberite.**

HENDRICKS, STERLING B.—**Concerning the Crystal Structure of the Clay Minerals Dickite and Halloysite.**

HESS, HARRY H. AND PHILLIPS, A. H.—**Ortho-pyroxenes of the Bushveld Type.**

HURLBUT, CORNELIUS S.—**Minerals Seen on the Northern Excursion of the 17th International Geological Congress.**

HURLBUT, CORNELIUS S.—**Adaptation of an Electrical Counter to Replace the Integrating Microscope Stage.**

KERR, PAUL F.—**Tungsten Mineralization at Oreana, Nevada.**

MARBLE, JOHN P.—**The Osseo, Canada, Meteorite.**

MCCONNELL, DUNCAN—**A Structural Investigation of the Isomorphism of the Apatite Group.**

MEEN, V. BEN—**Cleavage Luminescence in Mica.**

MEIER, ADOLPH E. AND TOMLINSON, W. HAROLD—**Harmotome from Delaware County, Pennsylvania. (A barium zeolite of hydrothermal origin.)**

MILLER, WILLIAM J.—**Genesis of Certain Adirondack Garnet Deposits.**

PABST, ADOLF—**Heavy Minerals in the Granitic Rocks of the Yosemite Region.**

PABST, ADOLF—**Crystal Structure and Density of Delafossite.**

PARSONS, A. L.—**Wave Surfaces and Indicatrices.**

PEACOCK, M. A.—**Goldschmidtine, a New Antimonide of Silver.**

RAMSDELL, L. S.—**Symmetry, unit cell and composition of hanksite.**

ROGERS, AUSTIN F. AND LAZARD CAHN—**Quartz with the Pinakoid Faces from Nathrop, Chaffee County, California.**

ROGERS, AUSTIN F.—**Diadochite, a Mineraloid from the New Idria Mine, San Benito County, California.**

ROGERS, AUSTIN F.—**Merosymmetry Versus Merohedrism.**

SMITH, HAROLD T. U.—**Models to Aid in Visualizing the Optical Properties of Crystals.**

THE ANNUAL SCIENCE EXHIBITION

The 1937 Annual Science Exhibition will be held in Murat Theatre, Indianapolis, December 27, 28, 29 and 30th. Through the medium of this Exhibition, which is held each year in connection with the annual meeting of the American Association for the Advancement of Science, scientists and those interested in science are privileged to learn of the latest developments in scientific research.

The affiliated societies of the A.A.A.S. are meeting within a short distance of Murat Theatre, thus all branches of science will be represented. Among the many interesting and varied research exhibits may be seen Professor J. Willard Hershey's synthetic gases and synthetic diamonds, and the fresh water sponges of Wisconsin shown by The Reverend Dr. Paul J. Carroll, S.J., of Marquette University. The Soil Erosion Survey of the U. S. Department of Agriculture will also have an exhibit of the work they are doing.

The showing of scientific sound films is being featured this year. Through the courtesy of Bell & Howell Company, jointly with E. L. Bruce Company, it will be possible for those attending the Exhibition to see such films as "Hidden Enemies" of the Bruce Co. Another film of great interest which may be seen will be Mr. L. A. Jones' "Motion Photomicrographs of Growing Crystals" which was shown for the first time at the eighteenth Annual Exhibition of the Royal Photographic Society of Great Britain. Members of the American Association for the Advancement of Science are requested to bring either long or short films which have been made in connection with research or hobby.

The commercial firms who serve science have cooperated enthusiastically and there will be many new ideas to be found among these exhibits. It is hoped that all interested in the progress of science will attend the Exhibition this year.

F. C. Brown, *Director of Exhibits*

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PRESIDENTIAL ADDRESS

Mente et Malleo Atque Catino, by Norman L. Bowen

A consideration of the three-fold character of investigation in mineral science and a plea for better coordination of effort in these activities.

(GSA 25) VOLCANOES OF THE MEDICINE LAKE HIGHLAND, CALIFORNIA*

BY CHARLES A. ANDERSON

The Medicine Lake Highland in northeastern California rises above the western margin of the Modoc lava plateau. The highland is a broad Pleistocene shield volcano of platy andesite, 20 miles in diameter, perched upon Pliocene plateau basalt (Warner basalt). Following the formation of the shield, a caldera, 4 to 6 miles across, formed by collapse. Renewed activity took place along the margins of the caldera, more viscous lava poured into it until the marginal volcanoes rose above the caldera walls and discharged lava down the outer slopes of the shield. An elliptical rampart of later volcanoes now marks the location of the original caldera walls. Recent volcanic activity is indicated by scattered parasitic basaltic cinder cones and the outpouring of basaltic lava from the outer flanks of the highland. The well-known Modoc lava beds include the northern cover of Recent basalt. Recent dacite and rhyolite flows have been erupted from the central portion of the highland; the rhyolitic flows were preceded by explosive eruptions which have showered the region with pumiceous ejecta. The last of these eruptions probably took place not more than 500 years ago.

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* Presented under the auspices of the Geological Society of America.

(SEG)(GSA 33) FLUORITE DEPOSITS IN WESTMORELAND, NEW HAMPSHIRE*

BY H. M. BANNERMAN AND R. E. STOIBER

The fluorite deposits in Westmoreland, New Hampshire, occur as fissure fillings in a series of tension fractures in granite gneiss. The veins being worked are from three to five feet in width, and some of them have been traced laterally five to six hundred feet. They dip approximately 70 degrees while the foliation of the gneiss in which they lie is generally quite flat. The veins are banded, crustified, and replete with open cavities. The fluorite is accompanied mainly by quartz, but considerable quantities of barite, calcite, dolomite, kaolin and sericite are present, and streaks of such sulphides as chalcopyrite, pyrite, sphalerite, and a little galena appear throughout the deposits, together with some finely crystallized malachite and smithsonite. The veins have suffered no appreciable deformation since their deposition. Data at hand suggest that they are of post-Paleozoic age, possibly Triassic.

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* Presented under the auspices of the Society of Economic Geologists.

(29) SURFACE REFLECTION AREAS IN WEISSENBERG PHOTOGRAPHS

BY M. J. BUERGER

A distinction is made between transmitted and surface x-ray reflections. The distribution of these two kinds of reflections on Weissenberg photographs is systematically derived for any crystal habit, for zero- and n-layer photographs, and for both normal beam and equi-inclination technique. Surface reflection areas have two important applications: (1) They are of aid in allowing for absorption in Weissenberg photographs. If the distribution of faces on the crystal is known, then the Weissenberg projection can be blocked out into contribution areas. (2) They provide an explanation for the distribution of background in Weissenberg photographs. Intense background patterns can be purposely developed under appropriate conditions and they are characteristic of the crystal form development. It is suggested that background patterns may be of aid in the surface goniometry of crystals having faces too small or too imperfectly developed for optical goniometric investigation.

(SEG)(GSA 31) SILICIFICATION TYPES ALONG THE HANGING WALL OF THE LONDON FAULT, MOSQUITO RANGE, COLORADO*†

BY ROBERT D. BUTLER‡

Dolomitic formations of Devonian and Mississippian age crop out on the east or hanging-wall side of the London fault south of the Alma district. The dolomites contain replacement ore bodies of barite-carbonate-pyrite-sphalerite-galena-tennantite, some of which are associated with vein quartz. The deposits occur within a rudely semicircular area truncated at the west by the London fault. A period of silicification of the dolomites preceded the formation of the ore minerals. Two types of replacement silica have been observed: (1) idiomorphic, in which the silica initially took the form of euhedral quarta crystals which became cemented by additional silica into an aggregate resembling a sandy limestone; (2) allotriomorphic, in which the structure ranges from a felted to a granular aggregate. A lateral zoning pattern of the ores has been recognized by utilizing serial variations of mineralogic and textural features, but the group of deposits as a whole are classed as "cooler" mesothermal. The silicification textures show areal variations which occupy positions in harmony with the zonal concept. Distribution of ore is not related to amount of silicification, but valuable ore bodies have been found only within a small area where certain silicified facies are present. The early epigenetic materials, silica, as well as the late, copper, lead, and silver minerals, are areally related to the position of the London fault and by their variations indicate the locus of thermal and solution supply.

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† Presented under the auspices of the Society of Economic Geologists.

‡ Introduced by W. H. Newhouse.

(4)(GSA 30) MINERAL DEPOSITS OF THE NORTHEASTERN PART OF THE HUMBOLDT RANGE, NEVADA

BY EUGENE N. CAMERON

The principal mineral deposits of the northeastern Humboldt Range are found in folded and faulted acid volcanics, overlying Triassic limestones, and Jura-Cretaceous (?) granite porphyry. The deposits are closely associated with major fault zones which trend roughly parallel to the folds. Among the exploited types, two are important: silver-bearing veins and stockworks, and quartz-stibnite veins.

Hypogene sulphides of the silver-bearing veins and stockworks include pyrite, sphalerite, freibergite, silver-bearing galena, and jamesonite, with minor amounts of arsenopyrite, stibnite, chalcopyrite, bournonite, and pyrargyrite. The principal gangue mineral is quartz. Calcite, barite, albite, apatite, scheelite, and epidote occur in places in the veins. Covellite, sooty argentite, and native silver appear to be supergene. The commercial value of the silver deposits is believed to be due to supergene enrichment.

Quartz-stibnite veins in limestone and rhyolite have been worked at several localities. The veins are of the replacement-fissure type and consist of stibnite replacing and filling fractures in massive quartz. Oxidation of a vein in Jackson Canyon yielded workable bodies of intermingled stibiconite and quartz.

Wall rocks of the deposits have been altered by silicification and sercitization, accompanied locally by development of pyrite, arsenopyrite, talc, chlorite, calcite, dolomite, albite, and apatite.

Structural features indicate a close relationship between mineralization and the Jura-Cretaceous (?) deformation which produced the major fault zones. The variety of forms exhibited by the deposits is believed to reflect the structural behavior of different kinds of wall rocks during deformation.

(GSA 24)

REGIONAL GRANITIZATION AND METAMORPHISM IN NEW ENGLAND*†

BY L. W. CURRIER

Origin of granites at Chelmsford-Westford, Massachusetts, and Milford, New Hampshire, is attributed to general intensive granitization of schists by dominantly hydromagmatic processes. Simple injection gneisses are negligible. Metasomatism has developed alkalic feldspars, quartz, and muscovite in definite paragenetic relations, displacing original bases (magnesium, iron, calcium, titanium). The probability is suggested that, driven into upper zones, these bases formed hornblende, garnet, biotite, epidote, and chlorite schists of common regional aspects. Petrographic and field studies of metamorphic rocks in east-central Vermont and adjacent areas to the east and southeast lead to the hypothesis that this process is a fundamental cause of the regional metamorphism. A broad zonal arrangement of granitic and metamorphic rocks is indicated, as follows: (1) a coastal belt of coarse intrusive granite stocks (Maine coast, Rockport, and Quincy, Massachusetts, et al.); (2) a broad belt to the west and northwest composed largely of replacement granites (Chelmsford, Milford); (3) another belt farther to the west and northwest, of dominantly pegmatitic aspects with highly mineralized schists, that contains commercial deposits of mica, garnet, feldspar, and fluorspar; and (4) still farther west and northwest, in western New Hampshire and eastern Vermont a belt of schists showing incipient granitization.

This hypothesis bespeaks a general batholithic invasion of eastern New England. The deeper, dominantly intrusive zone is exposed along the coast, but underlies the entire province east of the Green Mountains, though at progressively greater depths toward the west. The overlying zones of granitization and metamorphism are thus exposed in successive belts as outlined.

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* In part Geological Society project 49–33, and in part Geological Survey project on study of New England commercial granites.

† Presented under the auspices of the Geological Society of America.

(28)

THE SIGNIFICANCE OF CRYSTAL HABIT

BY J. D. H. DONNAY

Crystal habit depends on two kinds of factors: external (conditions of crystallization, presence of foreign ions, etc.) and internal (symmetry of the motif, structure, etc.). External factors may, for individual crystals, modify the normal habit imposed by internal factors for the species as a whole. A statistical survey of isolated habits usually leads to the recognition of the normal habit.

A study of crystal habit implies consideration of the following features: (1) presence or absence of forms (combinations); (2) relative importance (size, frequency, persistence) of forms; (3) relative importance of zones; (4) rules of zonal development (extinction criteria); (5) relative size of the various faces of any one form (malformation).

All these features but one (malformation) are satisfactorily explained by the influence of the space-group symmetry: (1) The habit may be predicted if the space-group (or even the diffraction symbol) is known. (2) The "morphological aspect" (or the diffraction symbol) and hence the space-group or possible space-groups may be predicted from the dominant habit features.

One reservation must be made. In many simple ionic structures, chemically different ions may act alike on the morphological development; in such cases, the crystal habit is the expression of the symmetry of ionic positions, regardless of their nature.

(25) STEREOSCOPIC CRYSTAL DRAWING

BY D. JEROME FISHER

Various projections are in use to facilitate the interpretation of crystal solids in terms of the measured angles between their faces or other significant planes, and their edges or analogous directions. The objective of crystal drawing is to furnish a strongly suggestive picture of a plane-faced solid. Of necessity angles will thus be distorted; the essential thing is that they appear to be correct. Various methods of attaining this end to greater or less degree are available; some choice should be made which combines to a maximum extent ease of construction with excellence of result. Stereoscopic pairs drawn in parallel perspective from a gnomonic base are easily prepared and are quite effective, mainly because the depth element in the projection of crystals need never be very large. Anaglyphs are more valuable because of their remarkable plastic properties. They are easily projected on a screen, but require special colored inks when drawn on paper.

(33) U-STAGE AXIAL ANGLE APPARATUS

BY D. JEROME FISHER

This apparatus replaces the inner plate of the regular universal stage. In addition is needed a special condensing lens which substitutes for the whole microscope substage. The new plate supports a small rotatable lower segment, the upper part of which is faced with polaroid. The inverted thin section is clamped to this plate by a ring into which may be placed either a rotatable upper segment or plate fitted with polaroid. Provision is made for synchronous rotation of the two polaroids. This apparatus permits the direct measurement of both 2V and 2E for not too-small crystals, though abnormally thick sections are needed for minerals of low birefringence. The apparatus should be of value in determining minerals by the V-E-*Beta* relationship, in obtaining the value of *Beta* for high-index biaxial minerals, in petrofabric analysis of reasonably coarse-grained rocks not only in terms of the *c*-axis direction of quartz but of both optic axes in feldspars, and it offers a very simple and convincing demonstration of classroom value that the interference figure is perhaps better regarded as a direction image.

(35) SODIUM BICARBONATE FROM SEARLES LAKE, CALIFORNIA

BY W. F. FOSHAG

Sodium bicarbonate has been encountered in large amounts in one of the deep wells drilled by the American Potash and Chemical Corporation in Searles Lake. It occurs with abundant gay-lussite as pockets or thin beds at depths from 120′ to the lowest portion of the well at 285′. The common form of occurrence is as an open reticulated mesh of twinned monoclinic crystals. $\alpha=1.375$, $\beta=1.505$, $\gamma=1.582$. Na_2O 36.74, Co_2 51.15, H_2O 10.76, R_2O_3 0.16, CaO 0.20, insol. 0.82. Sum 99.83. Samples of "nahcolite" from near Naples, consist of burkeite and a compound $NaCO_3 \cdot 3NaHCO_3$, hitherto unreported as a mineral and could account for the "nahcolite."

(27)

ORIENTED INCLUSIONS OF BROOKITE, ZIRCON, AND GARNET IN MUSCOVITE

BY CLIFFORD FRONDEL

Inclusions of brookite, zircon and garnet in muscovite are described with respect to their orientation to the mica. The method of investigation comprised: (1) the measurement of the crystallographic position of each crystal relative to the muscovite, (2) the plotting of the positions thus determined against frequency of occurrence, and (3) identification of positions of preferred orientation by statistical analysis of the frequency plots.

(5)

MAKING STRUCTURE MODELS

BY SAMUEL G. GORDON

Holes approximately the size of colored beads (on the scale of 1 cm. = 1 A°) representing atoms are punched in sheets of cellulose acetate (plastocele). The beads are cemented into the holes. The beaded sheets are assembled and placed in a crystal model made of thin glass plates taped at the edges. This mold is filled with partially polymerized "lucite." When hard, the glass mold is removed. The result is a clear glass-like crystal model enclosing beads showing the atomic structure.

(26)

THE NEW MINERAL HALL OF THE ACADEMY OF NATURAL SCIENCES OF PHILADELPHIA

BY SAMUEL G. GORDON

The mineral collections are now exhibited in newly designed *frameless* glass cases, lined with black velveteen, with concealed lighting (outside of the cases). Large specimens in wall cases are on individual glass shelves supported by concealed brackets. An effort has been made to set each specimen to the best advantage, many being upon glass stands. Labels are of cellulose acetate, printed with aluminum ink from type. Educational exhibits (What is Geology? What is a Mineral? What is a Crystal? etc.) are at the entrance. There is a crystal collection, and an index, with cross references, to the minerals in the cases. The new Fluorescence Exhibit will be automatically set in operation by visitors passing photoelectric cells. The cycle will be synchronized with a recording explanatory of the phenomena.

(2)

TWINNING IN GLAUBERITE

BY A. C. HAWKINS

Casts in soft solder have been made from cavities in the red Brunswick shales of Triassic age occurring at Milltown in Somerset County, New Jersey. The crystal forms are those of glauberite and in size and perfection they excel modern occurrences of the mineral. Twinning appears to be common, as interpenetration twins; some twinning is similar to the closely related species thenardite, but there appear to be other twinning laws involved. Full elucidation of the problem will require much careful study. (Twinning has never been reported in glauberite.)

(30)

CONCERNING THE CRYSTAL STRUCTURE OF THE CLAY MINERALS, DICKITE AND HALLOYSITE

BY STERLING B. HENDRICKS

Dickite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, is shown to have a somewhat random type of structure based upon the space group C_s^4–Cc. The structure suggested by J. W. Gruner (Zeits. Krist. Vol. *83*, p. 394 (1932)) is possibly correct save for this detail. Halloysite, $Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$, readily dehydrates to metahalloysite, $Al_2O_3 \cdot 2SiO_2. \cdot 2H_2O$, as was observed by M. Mehmel

(Zeits. Krist. Vol. *90*, p. 35 (1935)). However it is shown that the hydrated mineral has $(OH)_4Al_2Si_2O_5$ and $2H_2O$ layers rather than separate $Al_2(OH)_6$ and $Si_2O_3(OH)_2$ layers as suggested by Mehmel.

(16) ORTHOPYROXENES OF THE BUSHVELD TYPE

BY H. H. HESS AND A. H. PHILLIPS

Orthopyroxenes of the Bushveld Complex and many similar plutonic intrusions have in many cases been described as monoclinic because of small extinction angles observed. This pyroxene, however, when oriented on a universal stage so that it is parallel to (100) or (010) shows parallel extinction, though in other positions the extinction may appear inclined.

A characteristic feature of this pyroxene is the occurrence of very fine parallel striations on many grains when observed under crossed nicols. These striations are extremely thin lamellae of another mineral of approximately the same mean index as the orthopyroxene but of higher birefringence. They are parallel to (010). Furthermore they extinguish at an angle near 35° on either side of the (010) plane of the orthopyroxene when a section of the latter is viewed parallel to its (100) plane. It seems fairly certain that these lamellae are a diopsidic clinopyroxene. They are so oriented with respect to the orthopyroxene that they have their C axes in common, but the *b* axis of the clinopyroxene coincides with the *a* axis of the othopyroxene.

Chemical analyses of these orthopyroxenes, show about 10% diopsidic molecules and a rough estimate of the total volume of the lamellae is also about 10% of the whole pyroxene. This type of orthopyroxene is very common in plutonic rocks but never occurs, so far as the writer is aware, in volcanic rocks, though orthopyroxenes of volcanic rocks show the same proportion of diopsidic molecules. It is, therefore, suggested that the lamellae represent an ex-solution phenomenon which takes place with slow cooling but is prevented by rapid cooling.

The lamellae explain a part of the observed extinction angles as a result of the composite effect of the lamellae and orthopyroxene host when viewed in certain orientations. The remainder of the observed extinction angles is simply due to the orientation of the mineral. Any orthorhombic crystal with prismatic cleavage probably will give extinction angles in certain orientations.

(SEG)(GSA 32) EXPERIMENTS BEARING ON THE RELATION OF PYRRHOTITE TO OTHER SULPHIDES*

BY R. L. HEWITT AND G. M. SCHWARTZ

The problem of the existence of solid solutions between pyrrhotite and pentlandite, chalcopyrite, galena, and sphalerite was investigated by the heat treatment of suitable ores. Pentlandite was put into solid solution in pyrrhotite above 425 degrees C. and upon slow cooling from 800 degrees C. it unmixed. The unmixed pentlandite oriented itself around pyrrhotite grain boundaries and under high magnifications was observed to contain oriented laths of a mineral tentatively called pyrrhotite. The formation of these laths may be caused by the unmixing of a solid solution of pyrrhotite in pentlandite or by the breakdown of pentlandite expelling pyrrhotite.

Pyrrhotite and chalcopyrite form two solid solutions. Pyrrhotite will dissolve in chalocopyrite above 300 degrees C. The two minerals then react to form chalcopyrite which makes a very fine intergrowth with chalcopyrite in an aureole about pyrrhotite masses in the samples treated. Above 600 degrees C. chalcopyrite will dissolve in pyrrhotite and upon unmixing forms oriented laths in the pyrrhotite.

The eutectic intergrowth formed by pyrrhotite and galena has a composition of approximately 71 per cent galena and 29 per cent pyrrhotite by weight. The eutectic temperature lies between 765 and 775 degrees C. The variation between these figures and those for the artificial PbS-FeS system may be caused by impurities.

Crystallographic intergrowths between pyrrhotite and sphalerite were never produced although such intergrowths have been described and observed in many ores and it is assumed that hydrothermal conditions lower the temperature of formation for such intergrowths considerably below that required in a dry melt.

Small crystals of pyrrhotite, chalcopyrite, and galena were formed and the evidence indicates that they were produced by volatilization and subsequent deposition.

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* Presented under the auspices of the Society of Economic Geologists.

(2)(GSA 23)

STRUCTURE OF THE CALUMET STOCK, COLORADO

BY ARTHUR L. HOWLAND

The Calumet stock, of granodioritic composition, lies at the southern end of the Mosquito Range, about 8 miles northeast of the town of Salida. Its outcrop is about 12 miles in a north-south direction and has a maximum width of slightly over 5 miles, but the outcrop of the southern end is separated from the outcrop of the main mass by overlying Tertiary volcanics. The long axis of the intrusion coincides with a synclinal axis in the Paleozoic rocks. A study of the well-developed platy structure in the intrusive indicates that it has spread out sill-like into the Paleozoic beds, the platy structure being parallel to the steeply or gently dipping sediments on either side.

(6)

ADAPTATION OF AN ELECTRICAL COUNTER TO REPLACE THE INTEGRATING MICROSCOPE STAGE

BY CORNELIUS S. HURLBUT, JR.

This electrical tabulator, consisting of a series of counters, has several advantages over the old type integrating stage. The microscope is unencumbered except by a small mechanical stage to which the counter is connected by a flexible cable. The thin section lies directly on the microscope stage, enabling one to take interference figures. As many traverses as one wishes may be made across a thin section and the totals carried by the counters. A counter recording the total distance of traverse makes unnecessary the addition of the individual totals in calculating percentages.

15)

THE MINERALS SEEN ON THE NORTHERN EXCURSION OF THE 17TH INTERNATIONAL GEOLOGICAL CONGRESS

BY CORNELIUS S. HURLBUT, JR.

The "Northern Excursion" went north from Leningrad across Karelia and into the Kola Peninsula. In Karelia only two localities of mineralogical interest were visited, at Shunga and Chupa.

In the Kola Peninsula several interesting mineral localities were visited, most of which were associated with the alkaline rocks of that region. Of most interest were the many minerals and unusual associations found in the Khibine pluton. Here is found the apatite-nephelite association that is mined by the million tons; also several rare minerals are found there in sufficient quantity to warrant mining.

(1)(GSA 22)

RELATION BETWEEN PERIOD OF INTRUSION AND PRODUCTION OF FOLIATION IN A GRANITIC INTRUSIVE NEAR HANOVER, NEW HAMPSHIRE

BY EDWARD PECK KAISER

The granitic intrusive is largely gneissic, and is wrapped by schist bands. The intrusive boundary is not sharp, but rather consists of a zone of rocks intermediate in both texture and composition between the granitic gneisses and the schists.

Petrographic and field relations indicate that both foliation and linear alignment were produced after complete solidification of the intrusive. Petrofabric diagrams show a typical *b*-girdle with point maxima, indicating that the *b*-axis (linear direction in the rock) was an axis of rotation during deformation. Movement then was at right angles to the linear direction, rather than parallel to it.

Linear alignment, therefore, is not here a flow structure, but a tectonic structure. It may have followed flow structure in part, but some discrepancies are noted.

(3)(GSA 26) TUNGSTEN MINERALIZATION AT OREANA, NEVADA

BY PAUL F. KERR

The tungsten deposit at Oreana, Nevada, exhibits a number of characteristics not found in other commercial tungsten deposits in the United States. Beryl, oligoclase, albite, fluorite, phlogopite and quartz are prominently associated with scheelite in the ore. Garnet and epidote ordinarily so common in the contact metamorphic deposits of the western United States are virtually absent. Neither is the mineralization of the quartz-vein type which yields tungsten in a number of western localities. The scheelite mineralization at Oreana is considered pegmatitic, a type of occurrence unique among tungsten localities in the region.

Two forms of deposition have been observed. (1) Scheelite occurs in almost vertical pegmatite dikes cutting metadiorite. The dikes may be composed almost entirely of scheelite, of feldspar, of fluorite or of quartz. Sheelite in these dikes is associated chiefly with sodic plagioclase, phlogopite, and beryl. (2) Scheelite also occurs in lens-like masses along a contact between limestone and metadiorite, associated with sodic plagioclase and phlogopite. The contact plane is undulating but inclined at about 30 degrees, the metadiorite intrusive occurring above the contact plane, the limestone below.

Zones of silicification and zoisitization lead downward from the limestone-metadiorite contact within the limestone. Traces of scheelite have been found in these zones but no ore. It is believed, however, that these alteration zones in the limestone represent contributing channels leading to ore deposition above.

(19) THE OSSEO, CANADA, METEORITE

BY JOHN PUTNAM MARBLE

This kamacitic iron, a very coarse octahedrite, was found in the Temiskaming District, Ontario, Canada about 1934. It carries few troilite nodules, and schreibersite is rare. The Newmann lines are bent in places, which may indicate distortion in flight. An etched, polished section, and an analysis of a typical portion have been made.

(36) A STRUCTURAL INVESTIGATION OF THE ISOMORPHISM OF THE APATITE GROUP

BY DUNCAN MC CONNELL

One or more specimens of fluor-apatite, francolite (grodnolite and staffelite), dahllite (including podolite), dehrnite, lewistonite (including kurskite), fermorite, ellestadite, wilkeite, mangan-apatite and collophane (including quercyite) were examined by *x*-ray methods and were found to produce powder diagrams which differ from one another but slightly. The chemical analyses of these minerals indicate that calcium may be replaced by S, Si, As, V, and carbon; fluorine by chlorine and oxygen and by hydroxyl groups. The lattice dimensions of these minerals were determined and, whenever the analytical results seemed sufficiently reliable, the theoretical density was calculated and compared with the measured density.

This study has permitted certain conditions regarding the nomenclature of these minerals and has resulted in an explanation of carbonate-apatites, alkali-apatites and oxy-apatite. All of these types of substitution can be explained in terms of the structure of fluorapatite.

These substances are all members of various isomorphous series of the apatite group, but only in several instances have the end-members been discovered. Besides fluor-apatite the only ones known are hydroxy-apatite (1935) and ellestadite (1937). It is not possible to calculate the compositions of the end-members in most cases because some of the ions (C, OH, F, et al.) can enter the structure in more than one sort of ionic position and the relative distribution between the several positions may vary with the amount of the ion present. Furthermore, one type of ionic substitution may be mutually dependent upon another type, producing isomorphous mixtures of extreme complexity.

(24) CLEAVAGE-LUMINESCENCE IN MICA

BY V. B. MEEN

Mica from Kilmar, Quebec, was found to luminesce when split. The optical properties and chemical composition are discussed. Certain other micas were found to show the same phenomenon.

(18) HARMOTOME FROM DELAWARE COUNTY, PENNSYLVANIA, A BARIUM ZEOLITE OF HYDROTHERMAL ORIGIN

BY ADOLPH E. MEIER AND W. HAROLD TOMLINSON

Small creamy white to transparent cruciform penetration twins of harmotome were found lining the joint seams of a tongue of gabbroid rock in serpentine near Glen Riddle, Pennsylvania. Identity of the mineral was confirmed by optical measurements and chemical analysis. Closer study of the rock exposure revealed an interesting suite of associated minerals such as barium potash feldspars, corundum, and montmorillonite.* The results of the Study indicate a fairly low temperature, hydrothermal origin for the harmotome.

The paper is divided into two parts. The first part gives a brief description of field and petrographic relationships necessary for an understanding of the discussion of the paragenesis of the harmotome which follows. The second part covers optical and crystallographic measurements, and chemical analysis of the harmotome. Data obtained on loss of water with heating with attendant changes in optical properties, is also included. The bearing of the latter on the possible formation temperature of the harmotome is also discussed briefly. On the whole the general properties of the mineral seem to be within the limits of variation of data obtained on harmotome from other localities.

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* Montmorillonite has been discussed in the November, 1937 issue of the *American Mineralogist.* Origin of the corundum will be treated in a future paper.

(37) GENESIS OF CERTAIN ADIRONDACK GARNET DEPOSITS

BY WILLIAM J. MILLER

The garnet deposits discussed in this paper occur in northwestern Warren County, New York, and adjacent regions.

Twenty-five years ago the writer advocated a theory according to which the garnets were produced by action of quartz syenite magma upon inclusions of basic Grenville gneiss. This theory needs to be modified. The garnets with conspicuous reaction rims of hornblende seem to have been produced by action of quartz syenite magma upon metagabbro, and the garnets without reaction rims seem to have been produced by action of anorthosite magma upon metagabbro, followed by attack of the combination by syenite magma.

(23) SULPHATE MINERALS OF THE COMSTOCK LODE, NEVADA*

BY CHARLES MILTON AND W. D. JOHNSTON, JR.

The following sulphates have been identified in old mine workings of the Comstock Lode: gypsum, epsomite, copper-zinc-epsomite, goslarite, magnesia-goslarite, melanterite, zinc-magnesia-chalcanthite, pickeringite, coquimbite, alunogen, copiapite, voltaite, and rhomboclase. These minerals are being deposited in or above the Sutro Tunnel which drains the lode. Iron, copper, and zinc sulphates are deposited in or beneath veins containing hypogene pyrite, chalcopyrite, and sphalerite. No silver was found in the sulphates. Pickeringite and epsomite are most abundant in areas of highly altered wall rocks. Timbers on the Sutro Tunnel level are shredded by the growth of pickeringite and epsomite crystals between the wood fibers.

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(SEG)(GSA 27) THE UNWEATHERED MANGANESE DEPOSITS OF THE BATESVILLE DISTRICT, ARKANSAS*†

BY H. D. MISER AND D. F. HEWETT

Since its discovery, about 1849, the Batesville district has been the source of a large quantity of manganese oxides that occurred in clays residual from the weathering of the enclosing Fernvale limestone (Ordovician). Since 1928, however, a considerable quantity of manganese carbonate and hausmannite has been mined and shipped from tabular lenses that lie parallel with the bedding and near the top of the enclosing Fernvale limestone and, therefore, close to the overlying Cason shale (Ordovician), which contains nodules (Girvanella) that are rich in manganese carbonate. Although they are largely manganese carbonate, some bodies contain considerable hausmannite, as well as bementite, and neotocite. Accessory minerals include hematite, pyrite, barite, and fluorite. The form and distribution of some small bodies of carbonate, as well as the larger bodies, that have been mined indicate that they are related to fractures that cut across the Fernvale limestone but, so far as known, do not extend into the overlying and underlying formations.

It has been known for many years that unweathered Fernvale limestone, even remote from bodies of manganese oxide or carbonate, contains appreciable manganese carbonate that was probably deposited with the limestone. It seems probable, therefore, that the concentrated bodies of manganese carbonate now being explored were formed by the concentration of the manganese disseminated through the Fernvale limestone, although at present exotic sources cannot be completely dismissed. The widespread presence of bementite, which is only known in deposits of hydrothermal origin, as well as neotocite, barite, and fluorite, indicates that the waters that accomplished this concentration were warm rather than cold. Their source is obscure.

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(32) CRYSTAL STRUCTURE AND DENSITY OF DELAFOSSITE

BY ADOLF PABST

Ramdohr (Zentralblatt für Mineralogie (A) 289–303 (1937)) has taken the structure of delafossite, $CuFeO_2$, to be identical with that of artificial cuprous ferrite determined by Soller and Thompson (Phys. Rev. 47: 644, (1935)).

The structure belongs to the space group D_{3d}^{5}–$R\bar{3}\underline{m}$. The unit rhombohedron, $a = 5.96$ Å, $\alpha = 29°26'$, is assumed to contain one $CuFeO_2$. Atomic coordinates are given as: Cu (0, 0, 0); Fe ($\frac{1}{2}, \frac{1}{2}, \frac{1}{2}$); O (1/9, 1/9, 1/9) and (−1/9, −1/9, −1/9).

The density corresponding to this structure is 5.52, notably higher than the value 5.07 given for delafossite by Friedel.

The hexagonal cell corresponding to the rhombohedral cell of Soller and Thompson has an axial ratio of 5.645 or 3×1.882. This compares with Roger's value, 1.94 (A. J. S. 35: 290-294 (1913)) obtained on crystals from Bisbee.

Interplanar spacings calculated from powder diffraction patterns of delafossite from Bisbee, Arizona, and from Kimberley, Nevada, as well as a powder pattern of delafossite published without interpretation by Waldo (*American Mineralogist* 20: 575-597 (1935)) agree nicely with spacings calculated from Soller and Thompson's cell for cuprous ferrite.

(20) HEAVY MINERALS IN THE GRANITIC ROCKS OF THE YOSEMITE REGION

BY ADOLF PABST

A study of the minerals separated from granitic rocks of the Yosemite region by the use of heavy liquids revealed no unusual or unexpected constituents. In spite of the fact that all of the principal intrusives of the region have certain group characteristics in common a few of the rock types may be clearly distinguished by differences in the assemblage of accessory minerals.

The examination of basic inclusions for their accessory minerals again suggests a close genetic relation to the host rocks. No explanation of this is offered.

(10) YEATMANITE, A NEW MINERAL, AND SARKINITE FROM FRANKLIN, NEW JERSEY

BY CHARLES PALACHE, L. H. BAUER, AND HARRY BERMAN

Yeatmanite, $(Mn, Zn)_{16}Sb_2Si_4O_{29}$, is a new mineral from Franklin, N. J. It is triclinic, pseudo-orthorhombic, with multiple twinning on *b*(010) and macroscopic twinning on (023). Elements (*x*-ray): a:b:c=0.7811:1:0.4775. $\alpha=103°49'$; $\beta=101°45'$; $\gamma=87°12'$. Cleavage perfect || (100); H. 4, G. 4.80. Biaxial, negative; X near a[100], Y near b[010], $Z\wedge c[001]=3\frac{1}{2}°$. Indices (Na): nX=1.873, nY=1.905, nZ=1.910, all ± 003. 2V about 49°, $r<v$, dispersion moderate. Clove-brown crystalline plates embedded in willemite.

(12) WAVE SURFACES AND INDICATRICES

BY A. L. PARSONS

A graphical representation of the reciprocal relations between wave velocity and indices of refraction in air, isotropic substances, uniaxial and biaxial crystals. By the use of reciprocal circles and ellipses the indicatrix of biaxial crystals is shown to have a form similar to the wave surface with the optic axes emerging at the little depression where the circle representing β meets the ellipse whose semi major and semi minor axes are γ and α.

(14) GOLDSCHMIDTINE, A NEW ANTIMONIDE OF SILVER

BY M. A. PEACOCK

System and morphological lattice, orthorhombic—*C*; $a:b:c=0.6312:1:0.6860$. Thirteen forms. Habit, stout prismatic [001], pseudo-hexagonal, with dominant forms, *c*{001}, *b*{010}, *m*{110}. Twinning, on (110), in all crystals. Structural lattice, orthorhombic—*C*; $a_0=7.75\pm0.05$ Å, $b_0=12.32\pm0.05$ Å, $c_0=8.42\pm0.05$ Å; $a_0:b_0:c_0=0.629:1:0.683$; $V_0=804$ cubic Å. Specific gravity, 6.83 ± 0.03. $M_0=3328$. The base-centered cell contains $Ag_{20}Sb_{10}$. Cleavage, none. Hardness, $2\frac{1}{2}$. Scarcely sectile. Crystals tin-white to lead-gray; opaque. Polished surfaces homogeneous, tin-white, distinctly anisotropic. Analysis (Gonyer): Ag 64.78, Sb 35.01, S 0.06, Pb, As, Cu, Sn none=99.85. Composition Ag_2Sb. Occurs with native silver, ruby silver and galena on a specimen from Andreasberg, Harz. Named in memory of Victor Goldschmidt (1853–1933) of Heidelberg. Goldschmidtine differs in all its essential properties from those reliably determined on dyscrasite—Ag_3Sb.

(8) DIRECT PROJECTION OF OPTICAL FIGURES*

BY TERENCE T. QUIRKE

A detachable stage holding a semi-translucent hemispherical surface permits reading of optical angles (2E), and orientation of mineral grains by inspection. The attitude and azimuth of optic axes may be read from vertical and horizontal scales upon the hemisphere of projection. Projection is achieved by the use of a polaroid plate in the base of the accessory stage placed over a mineral or rock slide, thus superposing a flat analyzer over the convergent polarized light from sub-stage illumination.

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* Presented under the auspices of the Geological Society of America.

(31) THE SYMMETRY, UNIT CELL, AND COMPOSITION OF HANKSITE

BY LEWIS S. RAMSDELL

Laue photographs of hanksite show the symmetry C_{6h}, hence the actual symmetry may be C_{6h}, C_6 or C_{3h}. Since the crystals are neither trigonal nor hemimorphic in development, C_{6h} would seem the most probable. The unit cell is a very large one. Oscillation photographs about the a, b and c axes, together with powder photographs, give the values $a=20.92$Å and $c=21.18$Å, $a:c=1:1.012$. This cell contains 8 molecules of $9Na_2SO_4\cdot 2Na_2CO_3\cdot KCl$.

(SEG)(GSA 29) NICKEL CONTENT OF AN ALASKAN TROCTOLITE*†

BY JOHN C. REED

A troctolite sill about 126 feet thick lies in a thick sequence of greenstone schists, graphitic phyllites, and quartzites on Admiralty Island near Juneau, Alaska. Diorite or gabbro bodies are also present in the vicinity. The sill, called at the outcrop, the Mertie Lode, occupies a position near the crest of a large southeastward pitching anticline. The sill in its known extent is probably only a small part of a much larger body.

The sill is coarse grained, but has a diabasic texture. Measurements of volumetric proportions of the component minerals of the rock by means of traverses across thin sections show the rock, as represented by the thin sections, to contain about 62.3 per cent labradorite, 34.2 per cent olivine, 2.2 per cent pyroxene, 0.82 per cent pyrrhotite, 0.20 per cent magnetite, 0.13 per cent chalcopyrite and 0.06 per cent pentlandite.

The rock contains about 0.18 per cent chalcopyrite and 0.10 per cent pentlandite by weight. The copper content, therefore, is about 0.06 per cent and the nickel content about 0.025 per cent (the composition of pentlandite is not definite but the nickel content of that mineral used in the calculations was 24.65 per cent which was the nickel content of pentlandite from a not far distant locality on Yakobi Island analyzed by A. H. Phillips).

A chemical analysis by R. C. Wells of a panned concentrate from a chip sample of the sill showed 3½ times as much copper as nickel. This appears to check within reasonable limits of error of sampling and petrographic measurements, the ratio of copper to nickel or about 2½ to 1 obtained by petrographic measurements.

Assuming that the relative proportions of metallic minerals as determined petrographically is reasonably correct then a mixture of the opaque minerals of the sill in those proportions, with no silicates, would contain only 1.4 per cent nickel.

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† Presented under the auspices of the Society of Economic Geologists.

(17)

ON TARBUTTITE

BY WALLACE E. RICHMOND, JR.

Excellent crystals of tarbuttite, a basic zinc phosphate, from Broken Hill mines, Rhodesia, are triclinic: $a:b:c=0.6296:1:0.5971$; $\alpha=89°37\frac{1}{2}'$, $\beta=91°28\frac{1}{2}'$, $\gamma=107°41'$ (new elements derived from ten crystal measurements on the two-circle goniometer computed in the new position, the normal triclinic setting); twenty of the twenty-nine accepted forms were observed; also the new form $q\{\bar{1}02\}$ and the new but uncertain form $\{\bar{3}21\}$; ten reported forms were discredited; cleavage $\{010\}$ perfect; habit short prismatic approximating pseudo-isometric. *X*-ray measurements gave: $a_0=8.097$ Å, $b_0=12.91$ Å, $c_0=7.688$ Å; $\alpha=89°34\frac{1}{2}'$, $\beta=91°35\frac{1}{2}'$, $\gamma=107°47^1$; $a_0:b_0:c_0=0.6271:1:0.5957$. The pseudo-isometric lattice is a multiple lattice of the proper crystal lattice. From existing analyses and densities the unit cell contains $8[Zn_2PO_4(OH)]$.

New optical data:

	ϕ	ρ	n(Na)		
X(colorless)	7°	58°	1.660		Positive
Y(colorless)	−159	25°	1.705	±0.003	2V=50°±2°
Z(colorless)	− 86	80	1.713		

(38)

DIADOCHITE, A MINERALOID FROM THE NEW IDRIA MINE, SAN BENITO COUNTY, CALIFORNIA

BY AUSTIN F. ROGERS

A Yellow-brown, resin-like, massive material found in an old fill of one of the drifts of the New Idria quicksilver mine proves to be amorphous and so is called a mineraloid.

Chemical analyses reveal that it is a hydrous ferric sulfate-phosphate, analogous to the corresponding sulfate-arsenate, pitticite, which is a more common mineraloid.

A quantitative analysis leads to the formula: $2Fe_2O_3\cdot 3(SO_3,PO_5)\cdot 15H_2O$, which is surprisingly definite for a mineraloid.

This is apparently the first American occurrence of diadochite (phosphoreisensinter)

(11)

MEROSYMMETRY VERSUS MEROHEDRISM

BY AUSTIN F. ROGERS

Although Groth's names of crystal classes based upon general forms are superior to other names, it is often convenient to refer to the class with the maximum symmetry in any system and also to classes of lower-grade symmetry.

For this purpose the terms holohedral and merohedral have usually been used. The merohedral forms (hemihedral, tetartohedral, etc.) are said to be produced from the holohedral forms by suppression of certain faces and the extension of others.

Since the suppression of faces is always a *symmetrical* suppression, it seems advisable to substitute the suffix *-symmetric* for the suffix *-hedral*. Thus we have holosymmetric, merosymmetric, hemisymmetric, etc. (Symmetry is the key-note in the study of crystals.)

These terms were introduced by Story-Maskelyne in 1875 and elaborated upon in his classic, "Crystallography, a Treatise on the Morphology of Crystals" (1895). Story-Maskelyne's nomenclature of the crystal classes, however, is unnecessarily complicated.

A simple set of names based upon merosymmetry is presented as a list supplementary to class names based upon general forms.

(39)

QUARTZ WITH PINAKOID FACES FROM NATHROP, CHAFFEE COUNTY, COLORADO

BY AUSTIN F. ROGERS AND LAZARD CAHN

Minute α-quartz crystals of prismatic habit with the forms $\{10\bar{1}0\}$, $\{20\bar{2}1\}$, $\{02\bar{2}1\}$, $\{10\bar{1}1\}$, $\{01\bar{1}1\}$, $\{20\bar{2}3\}$, $\{02\bar{2}3\}$, and $\{0001\}$ from Ruby Mtn., Chaffee County, Colorado, show very prominent pinakoidal faces. This is one of the very few authentic occurrences of the pinakoid on quartz.

(34) AN OPTICAL ANALYSIS OF IMMERSION METHODS WITH REFERENCE TO THE SENSITIVITY OF THE DOUBLE-DIAPHRAGM METHOD

BY CHARLES P SAYLOR

Employing monochromatic light and the double-diaphragm method of oblique illumination, a difference of 0.00015 between the refractive index of a particle and an immersion liquid can be seen without difficulty (J. Research NBS 15, 277 (1935); RP 829). This results in a sensitivity in the determination of refractive indexes that cannot be attained in practice with the ordinary method of oblique illumination or with central illumination. An analysis of the optical mechanisms involved in image formation under these circumstances makes clear the reasons for the greater sensitivity and emphasizes the importance of adjusting the condenser diaphragm vertically so that its image is strictly in the plane of the objective diaphragm.

(13) AN OCCURRENCE OF LARGE HALITE CRYSTALS

BY CHESTER B. SLAWSON

Rock salt is mined at Detroit from a continuous seam of horizontally stratified salt. Large masses of clear transparent halite crystals are occasionally encountered. These masses average from ten to fifteen feet across and are associated with lenses of fine dense dolomite which generally lie beneath the halite crystals. Single crystals two feet or more in diameter are not uncommon. In many instances blasting has caused the separation of crystals along the dodecahedral gliding plane to be more extensively developed than separation along the cubical cleavage. While these masses occur throughout the mine they are most frequently found along two zones of alignment.

(7) MODELS TO AID IN VISUALIZING THE OPTICAL PROPERTIES OF CRYSTALS

BY HAROLD T. U. SMITH

By means of transparent celluloid models, the following relations are illustrated: (1) orientation of the uniaxial indicatrix in hexagonal and tetragonal crystals, as shown by wooden ellipsoids inclosed in crystal models; (2) orientation of the biaxial indicatrix in orthorhombic and monoclinic crystals, similarly shown; (3) vibration directions in an orthorhombic crystal; (4) the uniaxial indicatrix in skeleton form; (5) the biaxial indicatrix in skeleton form; (6) the relation of the uniaxial indicatrix to the ray-surfaces, in three mutually perpendicular cross sections; (7) the relation of the biaxial indicatrix to the ray-surface, in the three principal sections.

(40) ORIGIN OF FIBROUS GYPSUM VEINS IN THE LYKINS AND MORRISON FORMATIONS OF COLORADO

BY LINCOLN R. THIESMEYER

Near Table Mountain, eighteen miles southwest of Colorado Springs, veins of fibrous gypsum are locally abundant in the Lykins and Morrison formations. Three types of veins are distinguished, as follows: one group of cross-fiber veins forms subparallel networks within a massive alabaster member of the Morrison and roughly parallel to its bedding; another set of cross-fiber veins crosses these and extends downward into lower members of the Morrison and into the Lykins redbeds; a third set follows the bedding-planes of arenaceous red shales in the Lykins. The gypsum of this third set varies from fibrous to lamellar, but the elongation of the crystals is roughly parallel to the dip of the beds, so that the grains lie parallel to the vein walls. The veins contain partings of shale and display most of the features common to fibrous veins elsewhere. Their restriction to the central portions of small, local, anticlinal structures indicates that they were formed subsequent to the regional deformation and followed fractures resulting from it. Limitation of the veins to a stratigraphic position everywhere within or below massive beds of gypsum in the Morrison suggests that the latter supplied the vein material to downward-migrating groundwaters. Several lines of evidence indicate that the fibrous structures are not a result of lateral secretion through the wallrocks, as has been proposed for many fibrous mineral occurrences. Similar phenomena and conclusions are reported for fibrous gypsum veins later observed near Rapid City, South Dakota.

(21) HEAVY MINERAL METHODS APPLIED TO THE PRE-CAMBRIAN ROCKS OF THE SOUTH SHORE OF LAKE SUPERIOR*

BY STANLEY A. TYLER AND RALPH W. MARSDEN†

On the south shore of Lake Superior, pre-Huronian and Keweenawan igneous rocks may be readily distinguished by the variety of zircon present. A third period of intrusion post-Huronian–pre-Keweenawan is postulated and it is thought that rocks of this age may be distinguished from those of the other two periods. The pre-Huronian rocks are characterized by a purple zircon similar to those described by Mackie from the pre-Cambrian of Scotland. The post-Huronian–pre-Keweenawan rocks are characterized by a weakly birefringent zircon, and those of Keweenawan age by a euhedral, colorless to yellow zircon. The date of unroofing of these batholithic intrusions is clearly shown in the associated sediments.

The study of the heavy accessory minerals in the Keweenawan igneous rocks shows that the relative percentage of the minerals change with the rock type and for this reason relative percentages cannot be used as a basis for correlation. The variety of zircon remains essentially constant regardless of the composition, or the crystallization and cooling history of the rock.

The detrital heavy mineral suite in the Huronian sediments remains remarkably constant throughout, therefore individual formations cannot be distinguished by heavy mineral methods. However, a heavy mineral study may be used to distinguish Huronian sediments from those of Keweenawan age in this area.

A re-study of the Upper Keweenawan series of Wisconsin has been made and a revision of the sequence advanced, which is conformable with the field occurrence and the heavy mineral studies. The heavy minerals may be used to distinguish the Oronto from the Bayfield group.

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* Presented under the auspices of the Geological Society of America.

† Introduced by A. N. Winchell.

(SEG)(GSA 28) A PYROPHYLLITE DEPOSIT IN SOUTHEASTERN NEWFOUNDLAND*†

BY J. S. VHAY‡

Quartz-pyrophyllite schists occur in an area near Manuels, on the south side of Conception Bay, southeastern Newfoundland. The pyrophyllite has been formed by the hydrothermal alteration of sheared and silicified rocks of the pre-Cambrian Harbour Main volcanics near a granite contact; the volcanics here consist of rhyolite flows and some clastic material.

The schists consist of various proportions of quartz and pyrophyllite, and grade into large masses of nearly pure pyrophyllite; they exhibit a variety of textures, depending upon the structures of the original rocks. The typical quartz-pyrophyllite schist has quartose nodules in a matrix of pyrophyllite. Thin sections show coarse pyrophyllite along fractures, and a mat of fine pyrophyllite replacing both the original minerals and the secondary quartz. The flakes of pyrophyllite have a random orientation, and the schistosity is an inherited structure preserved by differential replacement on the planes of schistosity.

Three factors influenced the localization of the pyrophyllite, (a) the acidic composition of the host rock, (b) the sheared condition of the rock, which itself depended in part upon the original structures of the flows; the schistosity was best developed in the flow-banded, spherulitic, and flow-brecciated types of rhyolite rather than in the massive type; because of these factors the schists high in pyrophyllite tend to lie in elongated areas parallel to the strike of the flows, (c) proximity to fissures near the granite contact, which acted as channelways for the hydrothermal solutions.

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† Presented under the auspices of the Society of Economic Geologists.

‡ Introduced by T. B. Nolan.

(9)

OPTICAL METHODS OF MEASURING IN REFLECTED POLARIZED LIGHT (M. BEREK)

BY H. W. ZEILER

Microscopical analysis of opaque ores and minerals in reflected polarized light is generally confined to qualitative observations such as the color of the reflected light or the degree of anisotropism. M. Berek, a few years ago, developed a method of measuring photometrically the power of reflection of opaque minerals. However, a general method of determining optical "parameters" of such minerals—similar to the methods available for transmitted polarized light where optical character, birefringence, angle between the optical axes, etc., can be determined—did not exist for reflected polarized light. Even determinations of the directions of vibration were subject to grave errors because the equipment available did not produce sufficiently well-defined, homogeneous, plane polarized light.

Recently the equipment was improved, so that plane polarized light of the highest purity and of one single azimuth can be produced in the plane of the specimen. These improvements permitted the development of methods of determination of the effects of anisotropism in reflected polarized light. The measurements are carried out with a rotating mica compensator and a rotating analyzer. M. Berek succeeded in defining various optical "parameters" of opaque minerals which show sufficient differentiation for diagnostic purposes. Berek has published various articles and one booklet about this subject and it is the intention of the speaker to present a brief review of the contents of these publications and demonstrate the new equipment.

The basic principle of these measurements in reflected polarized light is as follows:

Due to the optical character of the mineral, the light which is reflected by its surface becomes elliptically polarized with a simultaneous rotation of the main axis of vibration in respect to the plane of vibration of the incident polarized light. The mineral is brought into two successive diagonal positions, whereupon the mica compensator measures the ellipticity of the reflected polarized light and the analyzer measures the angle of rotation of the main axis of vibration. These measurements are utilized for certain computations and lead to the determination of the optical symmetry (uniaxial or biaxial), the complex optical character, and other "parameters" pertaining to the mineral under investigation which lead to their diagnosis.